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THE EFFECT OF SHORT PERIOD VARIATIONS OF TEMPERATURE AND SALINITY ON CALCULATIONS IN DYNAMIC OCEANOGRAPHY

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INTRODUCTION[1]

This paper is a discussion of possible discrepancies in computations of ocean currents (based on horizontal variations of dynamic topography calculated from arbitrary deep lying reference surfaces), because of time variations of temperature and salinity at fixed depths in the sea (illustrated for a 24-hour period at "Atlantis" Station 2639; Fig. 1). The results contained herein, while based chiefly on information from the western North Atlantic, are of general applicability, since time variations of the same order of magnitude have been observed over extensive areas of the Atlantic ocean. In selecting material for analysis of dynamic situations in the region concerned, consideration has been given only to those favorably located stations from which the structural features could most conveniently be obtained for illustrating the points in question. Consequently, in the illustrative profiles, details of structure, have, on occasion, purposely been omitted because extrapolation of data would have been required, the inclusion of which would serve no pertinent purpose to this discussion.

The short period fluctuations of temperature, salinity, and other oceanographic elements, at fixed depths in the sea appear to have been discussed first by Nansen (1902) on the basis of observations from the "Fram" expedition across the North Polar Basin in 1894; and during the following decade observations of similar phenomena in the Norwegian Sea suggested to Helland-Hansen and Nansen (1909) that a representative structural picture of the water mass could not be obtained on the basis of single isolated serial samplings. Still later, these same authors (Helland-Hansen and Nansen, 1926; Helland-Hansen, 1930) repeated observations on short period fluctuations of temperature and salinity in the eastern North Atlantic and further demonstrated that individual series of observations will not, as a rule, represent average conditions of a locality, so that, calculations of horizontal current velocities from the distribution of the field of mass will be such that at best only the main features of the flow pattern can be considered fairly trustworthy (much of the detail may be erroneous).

Investigations of internal wave phenomenon are not numerous but of sufficient geographic distribution as to suggest that the occurrence is general; as brought out, for instance, (in addition to the above) by investigations of Otto Pettersson (1933, etc.) in the coastal waters of Sweden and Denmark, by Knudsen (1911) in the Faero-Shetland Channel, by Defant (1932) in the South Atlantic and southern North Atlantic, and by Lek (1938) in the waters of the Netherland's East Indies. The status of the internal wave problem in 1931 was summarized by Ekman (1931) to whom the reader is referred. With the continued investigation of the problem, additional questions have been raised rather than answered, but in the light of recent theoretical investigations of Fjelstad (1933, 1937) significant information on the mechanism of the phenomenon is to be expected.[2]

Short period variations of oceanographic characteristics at fixed geometric depths from the physical sea level (illustrated by temperature variations at "Atlantis" Station

[1] This work was supported by a grant from the Penrose Fund of the American Philosophical Society.

[2] See also O. Pettersson (1907, 1909, 1921, etc.), Hans Pettersson (1916, 1920), Jacobsen (1913), and Kullenberg (1937) Additional discussions of theoretical aspects of the internal wave problem are by N. Zeilon (1911, 1912) and G. I. Taylor. (1931); while Fjelstad (1936) has made interesting applications of internal wave theory to analysis of tidal observations in the Arctic.

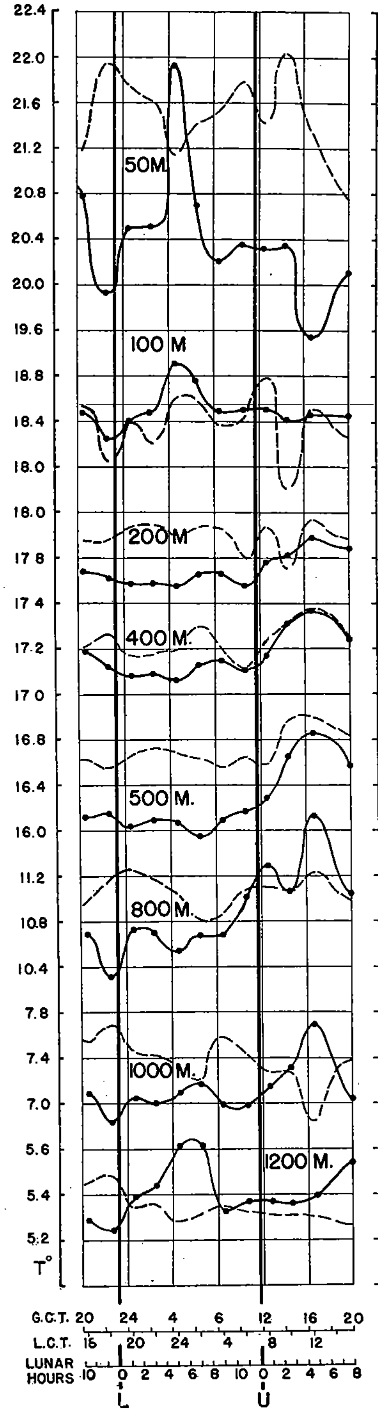

FIG. 1. Temperature (full line) and Oxygen (broken line) variations at fixed depths at "Atlantis" Station 2639 (66° 25′W, 37° 07′N) during a 24-hour period beginning about 15^h 30′ (L.C.T.), July 12, 1936.

2639; Fig. 1) may arise from one, or a combination of, short period vertical or horizontal displacements of water particles from mean positions, or from vortex motions of the water. The latter may apparently occur anywhere in the oceans, but probably more frequently in regions dominated by strong gradient currents (as the Gulf Stream system) so that time variations of oceanographic characteristics generally result either from vertical or from horizontal displacements (or their combination). But the latter will be significant only in regions of strongly sloping isopycnal surfaces (in the vicinity of gradient currents where periodically varying tidal currents are superimposed on the mean motions of the water layers). In general, over the greater part of the ocean space, isopycnal surfaces (and consequently temperature and salinity surfaces) are not strongly sloping, and it is to be presumed that the short period variations of oceanographic elements are caused by actual vertical displacements of the water particles.[3] Thus, for instance, in the western Atlantic, east of the Gulf Stream, where over any considerable distance gentle slopes of isopycnal surfaces usually prevail, vertical oscillations appear to be the chief cause of observed time variations of temperature, salinity, oxygen, etc. at fixed depths (measured from the sea surface). At "Atlantis" Station 2639 (66° 25′W, 35° 07′N; about 180 miles northwest of Bermuda) horizontal temperature gradients (Seiwell, 1937) are such that to account for apparent vertical oscillations of the 10° (777–831 meters depth) and 17° (408–482 meters depth) isotherms (Table 1) by means of horizontal displacements of the water masses, would require horizontal velocities ranging from 200 to more than 350 cms/sec. Likewise, in the southern North Atlantic ("Meteor" Station 288; 12° 38′N, 47° 36′W), where lateral temperature gradients were significantly greater than at "Atlantis" Station 2639, the displacement of sloping isothermal surfaces by lateral oscillating currents can hardly be used to explain the time variations of temperature at fixed levels since horizontal velocities of impossible values would be required (see Defant, 1932).

In practically every case, observations on internal waves appear to indicate 12 and 24 lunar hour periodicities; such, for instance, as brought out by Helland-Hansen (1930) and Helland-Hansen and Nansen (1926) in the North Atlantic, by Defant (1932) in the southern

[3] See discussions of this question by Helland-Hansen and Nansen (1926); Defant (1932) and Seiwell (1937).

North Atlantic and South Atlantic, and by our own investigations in the western Atlantic at Stations 2639 (66° 25′W, 35° 07′N; Seiwell, 1937; Table 1) and 2887 (34° 01′N, 65° 56′W; Seiwell, 1938). Other periods may also exist, as for instance, a prominent 8 lunar hour one at "Atlantis" Station 2639 (Table 1); and one of approximately 2.25 hours extracted by Defant (1932) from "Meteor" data in the southern Atlantic.

TABLE 1

Isotherm	Mean Depth	24^h Wave A	24^h Wave α	12^h Wave A	12^h Wave α	8^h Wave A	8^h Wave α
20°	55.4	7.4	5.2^h	1.8	5.8^h	5.6	5.2^h
17°	430.4	27.5	16.6^h	14.0	5.2^h	9.4	0.9^h
10°	802.4	24.7	17.4^h	4.1	10.4^h	2.3	6.4^h

Summary of amplitudes (A, meters) and phases (α, lunar hours) for vertical variations of the 20°, 17°, and 10° isotherms at "Atlantis" Station 2639 (66° 25′W, 35° 07′N) for the 24-hour period which began about 15^h 30′ (60, Meridian Time), July 12, 1936. Phase values referred to time of moon's lower culmination.

In discussing the difficulty of explaining an apparent tidal periodicity Ekman (1931) points out that results of observations of internal waves are not in agreement from the viewpoint of the equilibrium theory of tides, and further suggests that diurnal oscillations may not be tidal waves, but free inertial motions started by the wind or by some other disturbing factor. In such a case, the inertial waves should have a period of 12 pendulum hours.

SHORT PERIOD TEMPERATURE VARIATIONS AT FIXED DEPTHS IN THE SEA

General Temperature Variations in the Western Sargasso Sea as Represented by "Atlantis" Stations 2639 and 2887

The general nature of short period variations of oceanographic characteristics at fixed depths in the sea may be illustrated by temperature variations observed during four and one quarter days of continuous investigation (9^h 30′, July 9 to 15^h 45′, July 13, 1936) at "Atlantis" Station 2639 (66° 25′W, 35° 07′N).[4] During this time the spread of temperature ($t°_{max}-t°_{min}$) at fixed levels (between surface and 5000 meters) ranged up to 2.66°; as follows:

"At the surface, during the $4\frac{1}{4}$ day interval, the value of $t°_{max}-t°_{min}$ was only 0.30°, but at 50 meters depth, which lies in the summer thermocline, this value had increased to 2.66°; while below, in the relatively homogeneous water between 200 and 400 meters variations of only 0.31° to 0.36° were obtained. On entering the principal thermocline, which approximately lies between 400 and 1200 meters, the $t°_{max}-t°_{min}$ variations again become great, increasing from 0.90° at 500 meters depth to a value of 1.42° at 800

[4] Observations within a 5 mile radius of mean station position.
This and subsequent stations discussed in this report were carried out under ideal weather conditions, wire angles were small (usually less than 10°) and consequently errors in computed temperatures and sampling depths were at a minimum. Comparisons of pairs of thermometer readings by the different observers showed maximum differences in corrected temperatures rarely exceeded 0.01° to 0.02° and differences between computed sampling depths usually did not exceed 5 meters. Other evidence of the accuracy of computed sampling depths, based on simultaneous readings of protected and unprotected reversing thermometers, is shown by the fact that when the visible angle of the hydrographic wire did not exceed 5° the computed sampling depth for 1000 meters of wire was rarely less than 985 meters.

meters depth and then falling off continuously to 0.79° at 1100 meters and to 0.50° at 1200 meters depth. In still deeper water below the thermocline $t^\circ_{max}-t^\circ_{min}$ values continued to decrease with decreasing vertical temperature gradient; between 1400 and 2000 meters the values declined from 0.36° to 0.09° and continued to diminish still deeper until at 5000 meters depth the $t^\circ_{max}-t^\circ_{min}$ value was 0.02°, or the approximate error of the thermometers." (Seiwell, 1937; Page 29 and Table 13.)

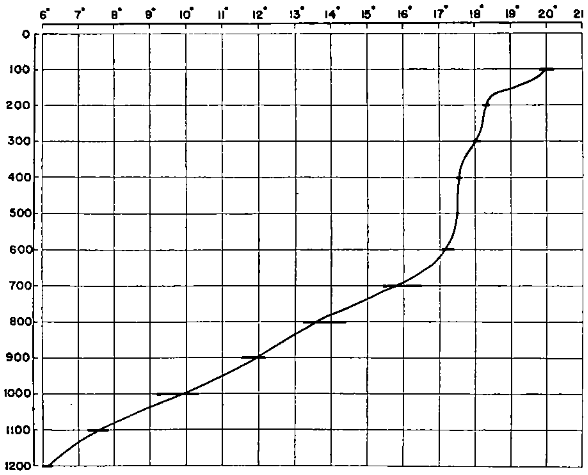

FIG. 2. Average vertical distribution of temperature at "Atlantis" Station 2887 (34° 01'N, 65° 56'W) based on continuous observations 23^h 16', June 19 to 13^h 34', June 22 and 7^h 57', June 24 to 04^h 22', June 28, 1937 (60° time); horizontal lines represent spreads of daily averages.

In this same locality, observations during the following year ("Atlantis" Station 2887: 34° 01'N, 65° 56'W; 23^h 16', June 19 to 13^h 34', June 22 and 7^h 57', June 24 to 04^h 22', June 28, 1937 60° time, Table 2) showed ranges in time variations of temperature at standard depths, of the same order of magnitude as at Station 2639 in 1936, thus corroborating the existence of the phenomenon in the waters west of Bermuda.

The summary of daily average temperatures at standard depths (for the 6 days of observation at Station 2887; Table 2) shows that minimum variations in the daily average of 0.04° to 0.18° occurred (between depths of 200 and 500 meters) where vertical variations of temperature were least and that maximum variations, up to 1.13°, are found where vertical temperature gradients are greatest (Fig. 2). Reference to Table 2 also brings out that (during the 6 days of observation) highest or lowest average daily temperatures at all depths did not occur on the same

TABLE 2

Depth	20		June 21		June 24		June 25		June 26		June 27		Average T°	Average Daily Range
	Daily average	T° range	Daily average	T° range	Daily average	T° range	Daily average	T° range	Daily average	T° range	Daily average	T° range		
100	19.86°	0.57°	20.14°	0.57°	19.91°	1.19°	19.79°	0.97°	19.94°	1.42°	19.85°	0.63°	19.92°	0.89°
200	18.27°	0.32°	18.27°	0.18°	18.35°	0.76°	18.22°	0.16°	18.23°	0.19°	18.27°	0.21°	18.27°	0.30°
300	18.11°	0.16°	18.05°	0.28°	18.03°	0.35°	17.99°	0.32°	17.93°	0.42°	17.98°	0.37°	18.02°	0.32°
400	17.60°	0.28°	17.48°	0.83°	17.54°	0.12°	17.52°	0.10°	17.49°	0.55°	17.54°	0.20°	17.53°	0.35°
500	17.44°	0.19°	17.49°	0.04°	17.48°	0.05°	17.46°	0.08°	17.44°	0.55°	17.46°	0.15°	17.46°	0.18°
600	17.06°	0.97°	17.34°	0.24°	17.10°	0.42°	17.14°	0.61°	17.13°	0.75°	17.04°	0.68°	17.13°	0.61°
700	15.90°	1.71°	16.43°	0.63°	15.50°	1.00°	15.61°	1.47°	15.60°	1.61°	15.41°	1.11°	15.74°	1.26°
800	13.77°	1.53°	14.34°	1.12°	13.39°	0.49°	13.38°	1.16°	13.29°	0.83°	13.21°	0.36°	13.56°	0.92°
900	11.50°	1.51°	12.01°	1.10°	12.02°	0.46°	12.05°	0.85°	12.14°	0.45°	12.02°	0.56°	11.96°	0.82°
1000	9.17°	1.39°	9.54°	1.20°	9.94°	1.13°	10.18°	1.21°	10.29°	1.18°	10.27°	0.94°	9.90°	1.18°
1100	7.25°	0.82°	7.48°	1.11°	7.63°	0.90°	7.76°	0.64°	7.79°	0.66°	7.75°	0.66°	7.61°	0.80°
1200	5.93°	0.27°	6.13°	1.10°	6.17°	0.98°	6.15°	0.36°	6.18°	0.33°	6.21°	0.57°	6.13°	0.60°

Summary of average daily temperatures and daily temperature ranges for standard depths at "Atlantis" Station 2887 (34° 01'N, 65° 56'W, 1937).

particular day; the largest number of highest mean values (4) occurred on June 21 and the largest number of lowest mean values (5) on June 20, but, also, on the latter day highest mean temperatures were observed at two depths.

A close connection exists between the spread of average daily temperatures and the daily temperature ranges, in that lower average daily ranges (0.18° to 0.35°) characterized depths (between 200 and 500 meters) where vertical variations of temperature were least, and higher average ranges, up to 1.26°, those depths where vertical temperature variations were greatest (Table 2).

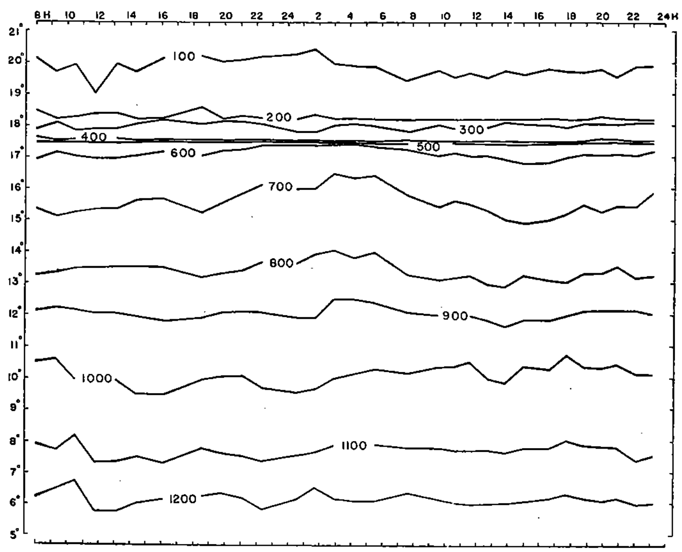

FIG. 3. Temperature variations at fixed depths at Station 2887 from 08h, June 24 to 23h, June 25.

Because of variation in phase and amplitude of vertical displacements superimposed on variable vertical temperature gradients, the time temperature variations at any depth will bear little relation to the time variation of average temperature over extended parts of the water column. At Station 2887, the average daily temperature of the water column (100 to 1200 meters was between 14.322° and 14.435°; a range, in general, less than that at most depths for the 6-day period.

UNIT TIME VARIATIONS AT STATION 2887

The unit time variations of temperature during June 24 and 25 (Figs. 1 and 3) at Station 2887 (Table 3), show that regardless of whether the absolute variations per hour or per time unit of 1h 18′ (average time between successive samplings) are considered, the higher values (and larger dispersions),[5] occur where thermal stratification is greatest. For this station the average absolute temperature variation per hour, at standard

TABLE 3

	June 24			June 25		
Depth	deg/time unit	Standard deviation	deg/hour	deg/time unit	Standard deviation	deg/hour
100	0.361	0.3164	0.253	0.195	0.1305	0.146
200	0.224	0.2154	0.157	0.036	0.0359	0.027
300	0.111	0.0738	0.078	0.082	0.0639	0.062
400	0.032	0.0319	0.022	0.022	0.0118	0.016
500	0.016	0.0126	0.011	0.021	0.0160	0.016
600	0.110	0.0547	0.077	0.082	0.0513	0.062
700	0.192	0.1011	0.135	0.220	0.1332	0.165
800	0.141	0.0875	0.099	0.222	0.1612	0.166
900	0.122	0.0705	0.086	0.130	0.1110	0.098
1000	0.239	0.2090	0.168	0.198	0.1524	0.148
1100	0.308	0.2217	0.216	0.108	0.1061	0.081
1200	0.298	0.2828	0.188	0.097	0.0554	0.073

Summary of average absolute temperature variations per hour and per time unit (average time between successive samplings of the water column, 1h 18′); standard deviations refer to the latter, station 2887, June 24 and 25, 1936 (see text).

[5] Standard deviations of the mean temperature change per arbitrary time unit in Table 3, based on non-normal populations, do not have all the customary properties of this statistic.

depths, amounted to 16.2 per cent of the average daily temperature range for June 24 and 25.

From the standpoint of practical oceanography, the frequency and magnitude of

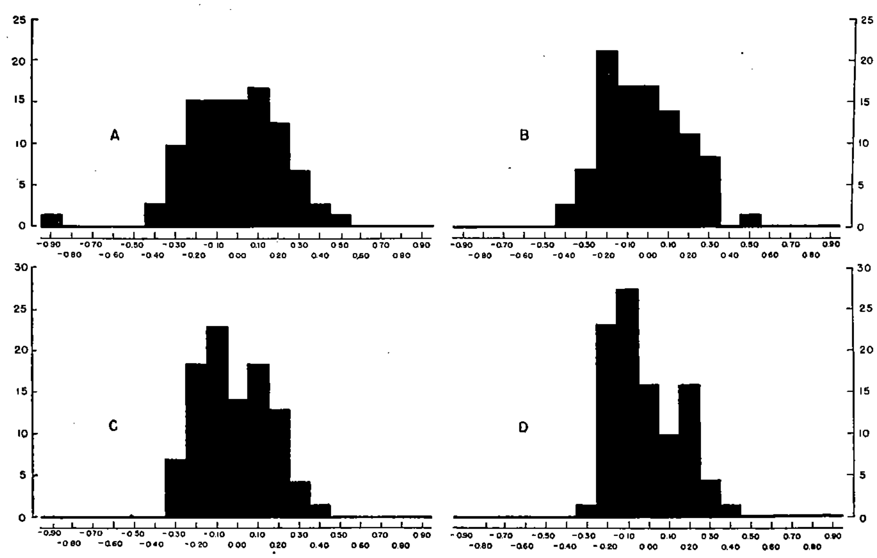

FIG. 4. Frequency distributions of departures of temperature from average values as observed for the period $7^h\ 57'$, June 24 to $4^h\ 22'$, June 28, 1937 at 100 meters depth, Station 2887; A=individual values; B=successive averages of two observations; C=successive averages of three observations; and D=successive averages of four observations.

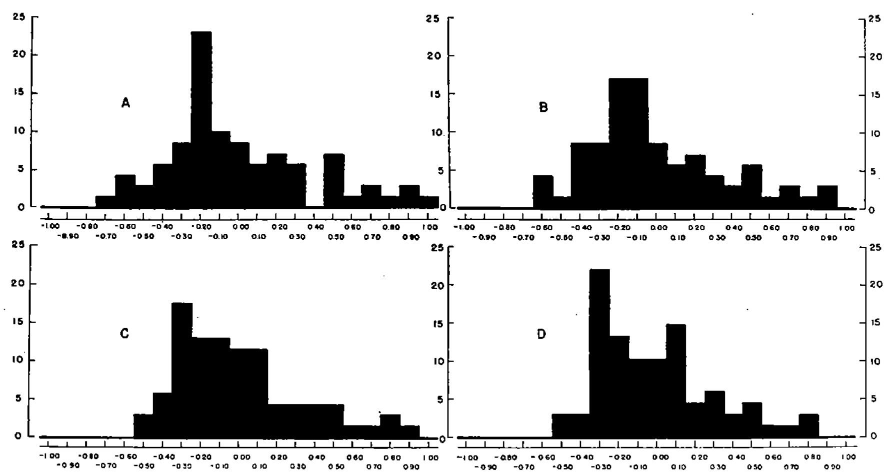

FIG. 5. Frequency distributions of departures of temperature from average values as observed for the period $7^h\ 57'$, June 24 to $4^h\ 22'$, June 28, 1937 at 700 meters depth, Station 2887; A=individual values; B=successive averages of two observations; C=successive averages of three observations; and D=successive averages of four observations.

departures, at standard depths, of temperature and salinity from mean values during the time required for a hydrographic survey of a region are questions of obvious concern.

In analyzing these variations (which result from internal wave mechanism), however, caution must be exercised because the observations do not readily lend themselves to analysis by the usual methods of mathematical statistics, since they are not mutually independent; in a continuous series, each observation is correlated with succeeding observations and only the very first of the series can be conceived of as being randomly determined. Hence, while accurate estimations of the population (used in the statistical sense) from the sample are uncertain, consideration of frequency distributions of temperature departures (separated by an average time interval of $1^h 18'$) from the mean values for the four day period (June 24 to 27) at Station 2887 at selected depths (100, 700, 900 and 1200 meters, having large daily temperature ranges) gives the following results:

100 Meters (*Fig. 4*). This depth, in the summer thermocline, had departures from the mean spreading between $-0.95°$ and $0.54°$. Probabilities of drawing an observation deviating from the mean by $-0.25°$ to $0.24°$ are nearly equal. The average of two, three, and four successive observations alters the distribution, chiefly, in clubbing together frequencies at the tails of the curve with increases in central tendency as shown by the progressive increases in frequency of departures falling between the limits $-0.25°$ to $0.24°$ (75.1%, 80.4%, 87.2%, 92.6%), but the frequency of occurrence of the smallest deviation from the mean (mid class mark: $-0.05°$ to $0.04°$) remained nearly constant (14.2%–16.9%) with successive averaging.

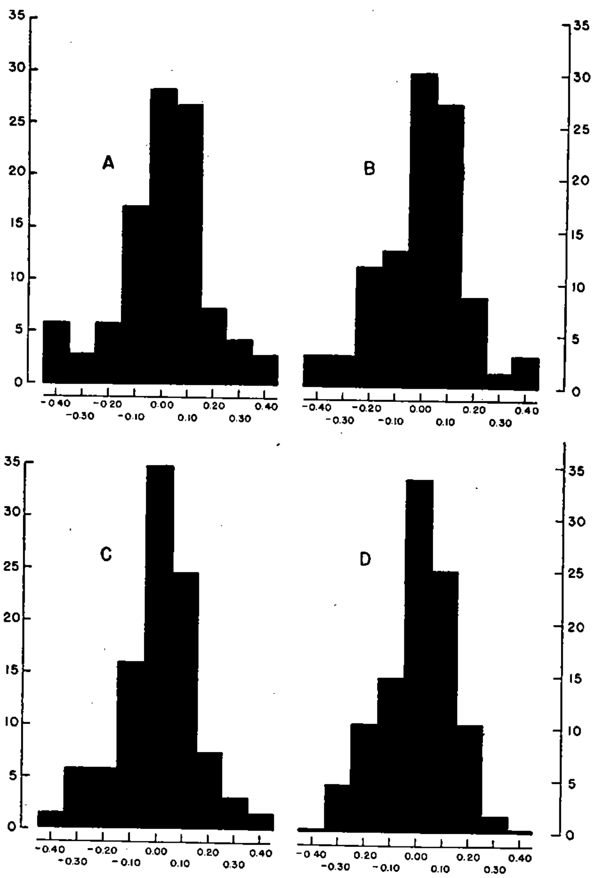

FIG. 6. Frequency distributions of departures of temperature from average values as observed for the period $7^h\ 57'$, June 24 to $4^h\ 22'$, June 28, 1937 at 900 meters depth, Station 2887; A=individual values; B=successive averages of two observations; C=successive averages of three observations; and D=successive averages of four observations.

700 Meters (*Fig. 5*). This depth, in the upper levels of the permanent thermocline, had temperature departures from the mean value more irregular and larger than at 100 meters; spreading between $-0.75°$ and $1.04°$. Successive averages of 2, 3, and 4 observations resulted in a continued irregularity of the distribution with no increase toward a central tendency (the frequency of the middle class value increased only from 8.6% to 11.6%) and some clubbing together of frequencies at the tails of the curve; the spread for averages of four successive observations having decreased to the limits between $-0.55°$ and $0.84°$.

900 Meters (*Fig. 6*). This depth, lying near the central part of the permanent thermocline, had a frequency distribution of departures from the mean lying between $-0.45°$ and $0.44°$, and the mid class values representing smallest departures from the mean

(−0.05° to 0.04°) occurred most frequently. Averaging of successive values of departures (up to 4) reduced and clubbed together frequencies at the tails of the curve and increased the probability of occurrence of the middle class value from 28.2% to 34.8%.

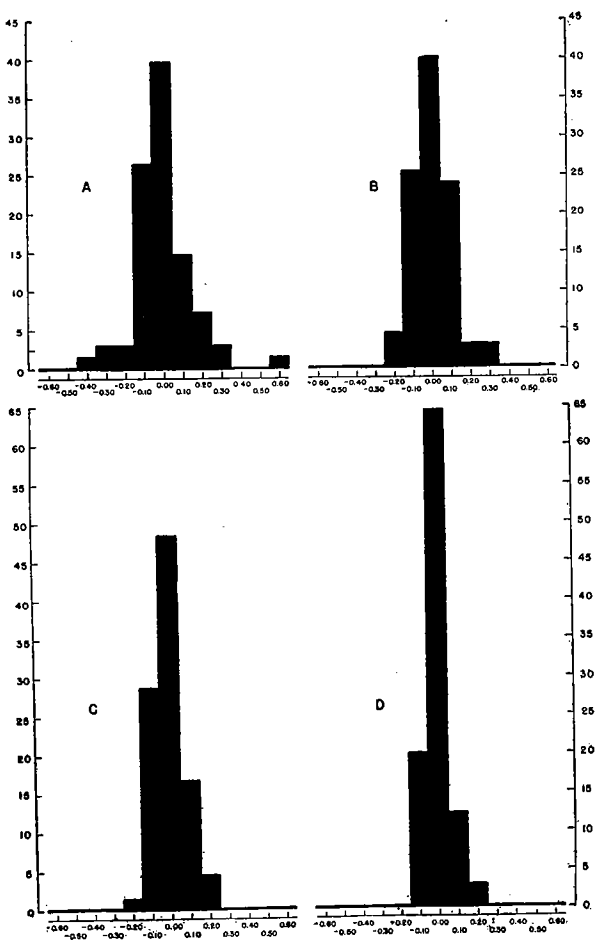

FIG. 7. Frequency distributions of departures of temperature from average values as observed for the period $7^h\ 57'$, June 24 to $4^h\ 22'$, June 28, 1937 at 1200 meters depth, Station 2887; A=individual values; B=successive averages of two observations; C=successive averages of three observations; and D=successive averages of four observations.

1000 Meters (*Fig. 7*). At this depth, lying near the lower part of the permanent thermocline, the frequency distribution of individual departures from the mean value lay between −0.45° and 0.64° and the middle class values (−0.05 to 0.04) occurred most frequent, far in excess of any others. Averaging of successive values increased the probability of occurrence of the middle class group, from 39.7% to 64.6%, as well as clubbing together the frequencies at the tails of the curves; for averages of four successive values the spread of departures from the mean was between −0.15° and 0.24°.

The foregoing frequency distributions bring out the following points regarding the character of short period temperature variations at constant depths along fixed verticals in the sea. These are:

1. Temperature oscillations at constant depths appear to result chiefly from a complicated controlling mechanism and are only partly random.

2. The directions and magnitudes of temperature variations differ from depth to depth.

3. Averages of 2, 3, or 4 successive observations somewhat reduce the magnitude of largest departures, and, in general, may be expected to increase the percental occurrence of smallest departures, but the effect does not seem to be sufficient to warrant use of average values in practical work.

4. Frequency distributions of individual departures may be used to estimate the approximate probabilities of temperature departures from average values, for periods of a few days, over areas of not too great extent.

By using frequency distributions of temperature and salinity departures from average values, for 25-hours or more, obtained from control stations in the region investigated, it is possible to approximate the expectancy of departures of various magnitudes at pertinent depths along fixed verticals, and to estimate the significance of observed horizontal departures as shown by individual samplings. The extent to which this suggestion may be of practical use will depend on the feasibility of establishing anchor stations and on the proportionate amount of time which can be allotted for the survey of control stations. In any case, the number of control stations need be determined by experience and by the general requirements of the problem investigated.

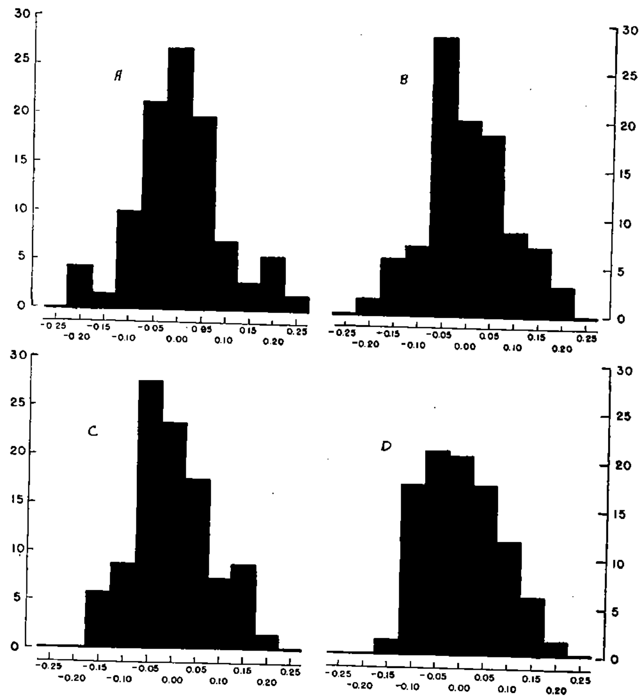

FIG. 8. Frequency distributions of departures of temperature from average values for the period 7^h 57′ June 24 to 4^h 22′ June 28, 1937 between 100 and 1200 meters depth, Station 2887; A=individual values; B=successive averages of two observations; C=successive averages of three observations; D=successive averages of four observations.

Because of the character of the internal wave mechanism, time variations of temperature are not identical at all depths, so, for example, temperature increases over one part of the water column may, during the same period, be offset by temperature decreases over another part; a phenomenon of significance when considering discrepancies produced in calculation of dynamic topographies from a deep lying reference level. At Station 2887, frequency distribution of individual departures of average temperatures of the water column, between 100 and 1200 meters, from the average for the four day period (June 24 to 27, Fig. 8) shows a maximum frequency, 26.7%, occurring at the mid class value (−0.02° to +0.02°), and a total range between −0.22° and +0.27°. The result of averaging two, three, and four successive observations is to club together frequencies at the tails of the curve and skew the distribution to the left to shift the maximum frequency to the cell bounded by values of −0.07 to −0.03 and decrease the middle class frequencies. Thus, comparison of this frequency distribution (Fig. 8) with those for individual depths (Figs. 4, 5, 6, 7) shows that because of its smaller range of departures, problems involving consideration of average temperature (or other characteristics) of a large part of the water column, will be subject to less incongruity than those based on temperatures at individual depths.

TIME VARIATIONS IN DYNAMIC CALCULATIONS AT INDIVIDUAL VERTICALS IN THE SEA

Hypothetical Example

Because of complicated conditions in the sea it is desirable to simplify the picture of the effect of time variations in calculated dynamic depths of isobaric surfaces, resulting from time changes of temperature and salinity at fixed depths, by a simple hypothetical example which approximates actual conditions.[6] Thus, in a hypothetical water column (of constant temperature salinity relationship), chosen to have an original temperature gradient decreasing linearly by 1° per 100 meters (between surface and 1200 meters), the changes in dynamic depth of standard isobaric surfaces, resulting from six variations of the original temperature distribution (Table 4) that are produced by superimposing an internal wave mechanism of magnitude illustrated by Figure 9, are shown in Figure 10.[7]

TABLE 4

Depth	Original T°	Salinity	1st Variation	2nd Variation	3rd Variation	4th Variation	5th Variation	6th Variation
0	18.0	36.46	18.0	18.0	18.0	18.0	18.0	18.0
100	17.0	36.36	17.5	16.5	16.5	17.5	17.5	16.5
200	16.0	36.17	16.5	15.5	15.5	16.5	16.5	15.5
300	15.0	36.00	15.5	14.5	14.5	15.5	15.0	15.0
400	14.0	35.82	14.5	13.5	13.5	14.5	13.5	14.5
500	13.0	35.65	13.5	12.5	12.5	13.5	12.5	13.5
600	12.0	35.52	12.5	11.5	12.0	12.0	12.0	12.0
700	11.0	35.39	11.5	10.5	11.5	10.5	11.5	10.5
800	10.0	35.28	10.5	9.5	10.5	9.5	10.5	9.5
900	9.0	35.19	9.5	8.5	9.5	8.5	9.0	9.0
1000	8.0	35.12	8.5	7.5	8.5	7.5	7.5	8.5
1100	7.0	35.08	7.5	6.5	7.5	6.5	6.5	7.5
1200	6.0	35.06	6.5	5.5	6.0	6.0	6.0	6.0
Average	12.0000		12.4792	11.5208	12.0000	12.0000	12.0000	12.0000

Original temperature and salinity distributions and six temperature variations of hypothetical example; for explanation see text.

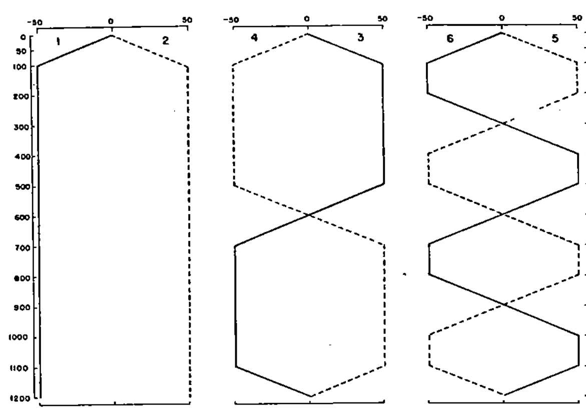

Fig. 9. Graphical representation of vertical displacement of water particles from original positions to produce variations 1 to 6 in hypothetical example; + = upward displacement, − = downward displacement.

Variations 1 and 2 (Table 4) represent the alterations in temperature that would result at different depths (exclusive of the surface), from vertical displacements of water particles by 50 meters from the original positions. In variations 3 and 4, nodes were assumed at 600 and 1200 meters, and temperature changes above 600 meters depth were

[6] These discussions are undertaken on the supposition that the effect of the internal wave mechanism does not sufficiently disturb the stationary condition of the sea to invalidate application of the Bjerknes dynamic method for calculating ocean currents.

[7] Corresponding salinity variations were scaled from an assumed temperature salinity relationship.

balanced by those below, so that while internal temperature variations were assumed to occur at fixed depths the average temperature for the entire water column would not depart from the original average of 12.000°. Likewise, for variations 5 and 6, nodes were assumed at 300, 600, 900, and 1200 meters, and due to the respective balancing of temperature variations above and below each node the mean temperatures of the entire water column remained constant (Fig. 9). The dynamic depths and heights (from 1200 decibars) of standard isobaric surfaces, as calculated from the original distribution, are given in Table 5, and departures characterizing each variation illustrated by Figure 10.

TABLE 5

Pressure D-bars	Dynamic Depth	Dynamic Height
0	0.000	1165.367
100	97.398	1067.969
200	194.742	970.625
300	292.035	873.332
400	389.277	776.090
500	486.470	678.897
600	583.613	581.754
700	680.704	484.663
800	777.743	387.624
900	874.730	290.637
1000	971.664	193.703
1100	1068.543	96.824
1200	1165.367	0.000

Dynamic depth (from the physical sea surface) and dynamic height (from 1200 decibars) of isobaric surfaces calculated from the original temperature and salinity distribution in the hypothetical example. See text.

The latter shows that for the first two variations (where the internal wave mechanism was assumed to act uniformly, with the same phase and amplitude over the water column) departures of dynamic depth from the original become continuously greater with increasing depth of the isobaric surfaces (from the physical sea surface); the difference in dynamic depth of the 1200 decibar surface between first and second variations being 11.7 dynamic centimeters. However, this simple uniform type of disturbance rarely, if ever, occurs in nature, and a closer approach to actual conditions is illustrated by variations 3, 4, 5, and 6 (which represent vertical variations of amplitude and phase). For the 3rd and 4th variations respective negative and positive departures of dynamic depths above the 600 decibar surface are identical with those for variations 2 and 1; maximum departures occur

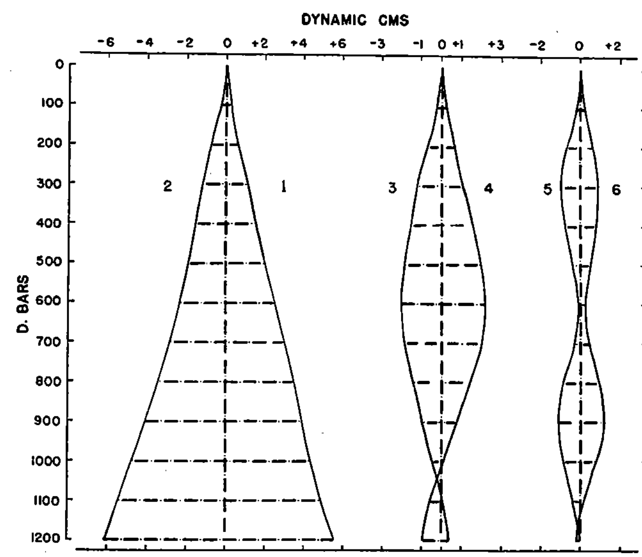

FIG. 10. Differences in dynamic depth of isobaric surfaces from the physical sea surface between original distribution and each of its six variations in the hypothetical example.

at the 600 decibar surface; still deeper, differences decrease and for the 1200 decibar surface the calculated difference in dynamic depth between these two variations is only 1.4 dynamic centimeters. Differences in dynamic depth of standard isobaric surfaces between the fifth and sixth variations become reversed at the nodes (fixed at 300, 600, 900, and 1200 decibars); with maximum differences occurring at 300 (1.9 cms) and 900 (2.3 cms) decibars, and minimum differences at 600 (0.3 cms) and 1200 (0.2 cms) decibars. However, computed horizontal velocities are usually not referred to the physical sea surface, but to some isobaric surface at great depths. Variations in dynamic heights of standard isobaric surfaces from the 1200 decibar surface for the hypothetical example are illustrated by Figure 11. We may next consider conditions in the Western Sargasso Sea as shown by "Atlantis" Station 2887.

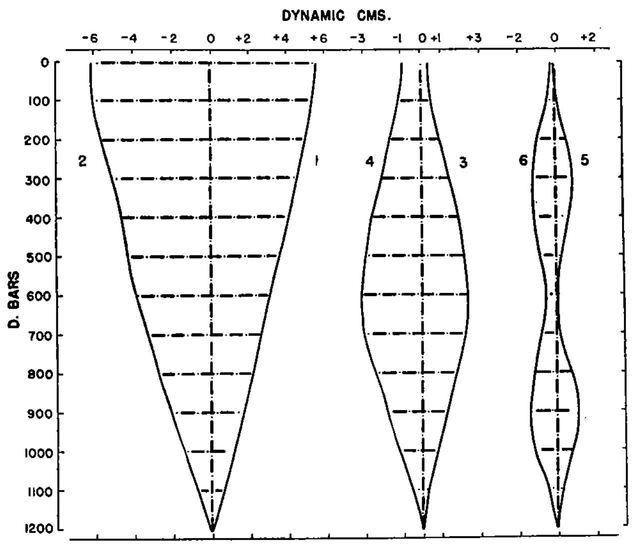

FIG. 11. Differences in dynamic height of isobaric surfaces for the 1200 decibar surface between original distribution and each of its six variations in the hypothetical example.

WESTERN SARGASSO SEA (24-HOUR PERIOD AT STATION 2887)

At this station between $7^h\ 57'$, June 24 and $7^h\ 33'$, June 25 (Fig. 12), the depths of standard isobaric surfaces, below 100 decibars, as calculated from observed temperatures (page 5) and the temperature salinity relationship[8] (Fig. 13) varied by 3.9 or more dynamic centimeters during the 24 hours. The largest variations (4.7 to 4.8 dynamic centimeters) occurring between 400 and 600 decibars. The significance of such variations in practical oceanography depends on the average dynamic topography of the region in question and is discussed on page 19. For the present example, the computed time variations in dynamic heights (or dynamic depths) of isobaric surfaces result from the uneven changes in dynamic thicknesses of isobaric sheets; details of which are given in Table 6, as anomalies of dynamic thickness of successive isobaric sheets (bounded by standard isobaric surfaces) for 9 samplings of the water column during the 24-hour period.[9] Columns headed Δ (in Table 6) represent differences in dynamic thicknesses between successive samplings (or the amounts of shrinking and stretching that isobaric sheets have undergone during the time interval). These show that changes in thickness of individual isobaric sheets frequently are greater than the total integrated changes in dynamic height at the sea surface of the whole water column. Thus, between series C ($13^h\ 01'$) and B ($10^h\ 25'$), the change in dynamic height, above the 1200

[8] At this and other similar stations, salinities were determined for only approximately 15 per cent of the samplings, and thence combined with corresponding temperatures to form the temperature-salinity relationship (Fig. 13) from which variations in salinity, to correspond with observed temperature variations, were scaled for computation of dynamic heights. The temperature-salinity relationship continued sufficiently steady throughout the series.

[9] Anomalies of dynamic height are obtained by successive summations of principal columns in Table 6.

decibar surface was only 0.20 dynamic centimeters (Tables 7), whereas thickness of isobaric sheets between 100–200 decibars and between 200–300 decibars increased 0.80 and 1.00 dynamic centimeters, respectively, while at the same time that between 1100 and 1200 decibars decreased 0.80 dynamic centimeters. Likewise, between series F (22^{h} 12′) and E (18^{h} 28′), variations in dynamic thickness of isobaric sheets, while not so large,

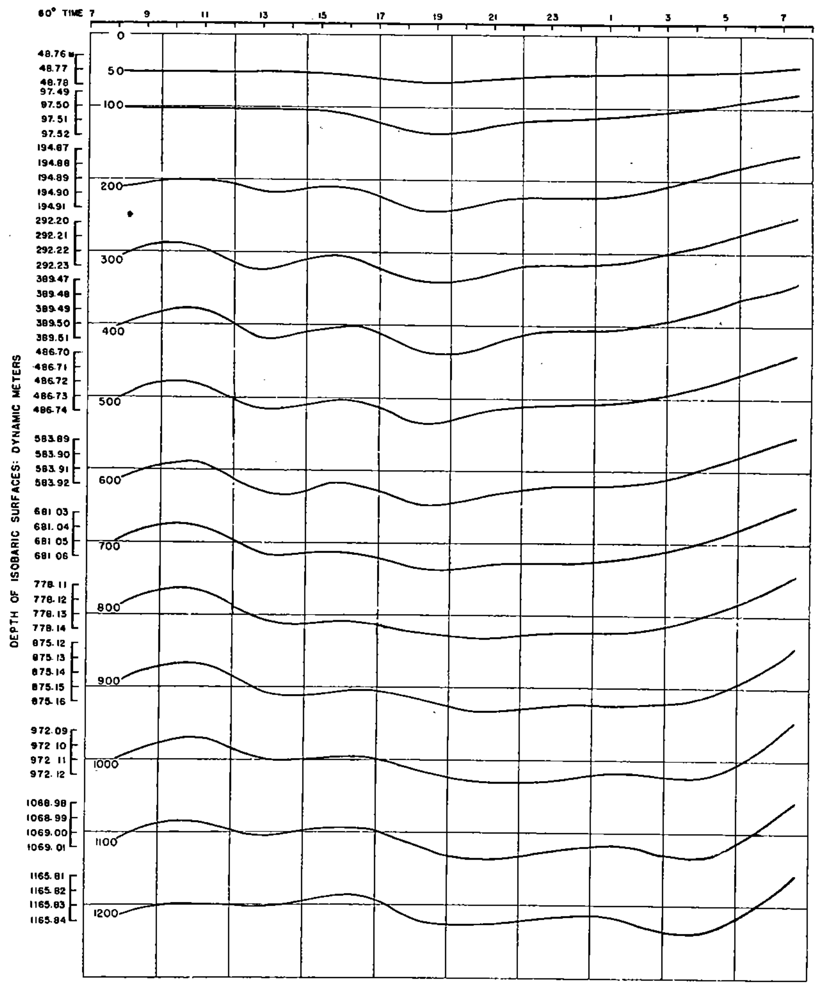

FIG. 12. Variations in dynamic depths (from physical sea surface) of standard isobaric surfaces during an approximate 24-hour period, 7^{h} 57′, June 24 to 7^{h} 33′, June 25, 1937 (60° time) at Station 2887.

were completely balanced, and summation of the total changes over the water column equaled zero. The time change between series H (04^{h} 05′) and I (07^{h} 33′) was the only case in which every single variation in dynamic thickness of the isobaric sheets was in the same (negative) direction, hence, summation gave the maximum effect. Greater amounts of variation occurred in the highly stable water above 200 decibars, and smaller where the water column was least stable (between 400 and 500 decibars).

Successive upward summations of time variation in dynamic thicknesses (Δ values

TABLE 6

Stratum D-Bars	*A* 6/24/37 $7^h\,57'$	*B−A* = Δ cms	*B* 6/24/37 $10^h\,25'$	*C−B* = Δ cms	*C* 6/24/37 $13^h\,01'$	*D−C* = Δ cms	*D* 6/24/37 $16^h\,02'$	*E−D* = Δ cms	*E* 6/24/37 $18^h\,28'$	*F−E* = Δ cms	*F* 6/24/37 $22^h\,12'$	*G−F* = Δ cms	*G* 6/25/37 $01^h\,37'$	*H−G* = Δ cms	*H* 6/25/37 $04^h\,05'$	*I−H* = Δ cms	*I* 6/25/37 $7^h\,33'$
0– 50	14.30	0.05	14.35	0.05	14.40	0.10	14.50	0.55	15.05	−0.40	14.65	−0.25	14.40	−0.10	14.30	−0.35	13.95
50– 100	11.60	−0.05	11.55	−0.05	11.50	0.20	11.70	0.70	12.40	−0.40	12.00	−0.10	11.90	−0.40	11.50	−0.70	10.80
100– 200	19.80	−0.60	19.20	0.80	20.00	−0.60	19.40	0.30	19.70	−0.20	19.50	0.40	19.90	−0.80	19.10	−0.60	18.50
200– 300	17.60	−0.40	17.20	1.00	18.20	−0.70	17.50	0.10	17.60	−0.20	17.40	−0.10	17.30	0.10	17.40	−0.30	17.10
300– 400	17.00	−0.20	16.80	0.20	17.00	0.10	17.10	0.00	17.10	−0.10	17.00	−0.20	16.80	0.20	17.00	−0.20	16.80
400– 500	16.80	0.00	16.80	−0.10	16.70	0.10	16.80	0.00	16.80	0.00	16.80	0.00	16.80	0.00	16.80	−0.10	16.70
500– 600	16.80	−0.10	16.70	0.10	16.80	0.20	17.00	−0.20	16.80	0.20	17.00	0.00	17.00	0.00	17.00	−0.10	16.90
600– 700	16.00	−0.10	15.90	0.10	16.00	0.40	16.40	−0.40	16.00	0.60	16.60	0.00	16.60	0.20	16.80	−0.30	16.50
700– 800	14.60	0.00	14.60	0.00	14.60	0.30	14.90	−0.30	14.60	0.60	15.20	0.10	15.30	0.10	15.40	−0.50	14.90
800– 900	13.69	0.00	13.60	−0.30	13.30	0.00	13.30	−0.10	13.20	0.50	13.70	−0.20	13.50	0.50	14.00	−0.50	13.50
900–1000	12.30	−0.20	12.10	−0.30	11.80	−0.30	11.50	0.20	11.70	0.20	11.90	−0.30	11.60	0.70	12.30	−0.20	12.10
1000–1100	10.00	0.10	10.10	−0.50	9.60	−0.40	9.20	0.50	9.70	−0.30	9.40	0.10	9.50	0.40	9.90	−0.10	9.80
1100–1200	7.70	0.60	8.30	−0.80	7.50	−0.20	7.30	0.40	7.70	−0.50	7.20	0.40	7.60	0.10	7.70	0.00	7.70

Time variations in anomalies of dynamic thickness of standard isobaric sheets during a 24-hour period $7^h\,57'$, June 24–$7^h\,33'$, June 25, 1937 at Station 2887

in Table 6) of isobaric sheets (Table 7) give the amount of variation in dynamic heights of standard isobaric surfaces as computed for successive samplings of the water column, and illustrate the magnitude of the discrepancies that may be induced in projections of dynamic topographies of these surfaces in a region such as the one represented by Station 2887 (page 6). Time variations in computed dynamic heights are irregular throughout the water column and those at the sea surface are not proportional to those at deeper lying isobaric surfaces. Thus, for example, between the series taken at $10^h\,25'$ and $13^h\,01'$ (Table 7), dynamic height of the sea surface increased 0.20 dynamic centimeters, but at the 700 and 800 decibar surfaces it decreased 1.90 dynamic centimeters; whereas, between $04^h\,05'$ and $7^h\,33'$, change in dynamic height of the sea surface was at a maximum (representing a continuous accumulation of changes in the deeper water).

Gulf Stream (24-Hour Period at Station 2855)

Dissimilarities between dynamic situations of Western Sargasso Sea and Gulf Stream system (along the American coast, Figs. 14, 15) are such that not only will vertical oscillations cause greater variations of oceanographic characteristics in the latter, but horizontal displacements of the water masses may also be effective (page 4). The present discussion is based on four series of observations (A: $21^h\,31'$, April 18; B: $03^h\,23'$, April 19; C: $11^h\,23'$, April 19; D: $15^h\,21'$, April 19, 1937) at "Atlantis" anchor Station 2855 in the Straits of Florida[10] (25° 37′N, 79° 51′W; depth 680 meters). Methods of calculation are identical with those used for Station 2887, except that (because of shallower depths) dynamic heights of isobaric surfaces are referred to the 600 decibar surface (Table 8). Due to unstable conditions in the surface layer, discussion refers to the water column below 100 decibars pressure. The variation in dynamic heights during the 24-

[10] These 4 samplings were selected as being sufficient for illustrative purposes from a series of 12 at Station 2855, which is one of a group of 5 anchor stations (2854–2858) discussed by Parr (1937) across the Florida Straits.

TABLE 7

Pressure D-Bars	($10^h 25'$) — ($7^h 57'$)	($13^h 01'$) — ($10^h 25'$)	($16^h 02'$) — ($13^h 01'$)	($18^h 28'$) — ($16^h 02'$)	($22^h 12'$) — ($18^h 28'$)	($01^h 37'$) — ($22^h 12'$)	($04^h 05'$) — ($01^h 37'$)	($7^h 33'$) — ($04^h 05'$)
0	−0.90	0.20	−0.80	1.75	0.00	−0.15	1.00	−3.90
50	−0.95	0.15	−0.90	1.20	0.40	0.10	1.10	−3.60
100	−0.90	0.20	−1.10	0.50	0.80	0.20	1.50	−2.90
200	−0.30	−0.60	−0.50	0.20	1.00	−0.20	2.30	−2.30
300	0.10	−1.60	0.20	0.10	1.20	−0.10	2.20	−2.00
400	0.30	−1.80	0.10	0.10	1.30	0.10	2.00	−1.80
500	0.30	−1.70	0.00	0.10	1.30	0.10	2.00	−1.70
600	0.40	−1.80	−0.20	0.30	1.10	0.10	2.00	−1.60
700	0.50	−1.90	−0.60	0.70	0.50	0.10	1.80	−1.30
800	0.50	−1.90	−0.90	1.00	−0.10	0.00	1.70	−0.80
900	0.50	−1.60	−0.90	1.10	−0.60	0.20	1.20	−0.30
1000	0.70	−1.30	−0.60	0.90	−0.80	0.50	0.50	−0.10
1100	0.60	−0.80	−0.20	0.40	−0.50	0.40	0.10	0.00
1200	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Time change in dynamic heights (dynamic centimeters) of standard isobaric surfaces between successive observation series during a 24-hour period at Station 2887 (calculated from a reference surface of 1200 decibars).

hour period (last column, Table 8) at 100 and 200 decibars, were 4.3 and 2.3 times the maxima[11] recorded for identical surfaces in the Sargasso Sea region, while time variations in isobaric sheet thicknesses (Table 9) were, on the average, 3.7 to 1.2 times those in the latter region. Perhaps noteworthy is the fact that positive and negative short period changes in dynamic thickness over the water column were not as irregular as at 2887, a result, possibly of the internal wave mechanism acting on a shallower water column or perhaps of a difference in character of the mechanism (page 4). However, whether or not the result of an internal wave mechanism, observations at Station 2855 indicate less balancing out, or cancelling, of time variations in dynamic thickness of isobaric sheets when large parts of the water column are considered. In only one case was balancing of plus and minus variations noticeable: between series C ($11^h 23'$) and D ($15^h 21'$) dynamic thicknesses of isobaric sheets increased between the 600 and 200 decibar surfaces and then decreased between 200 and 100 decibars.

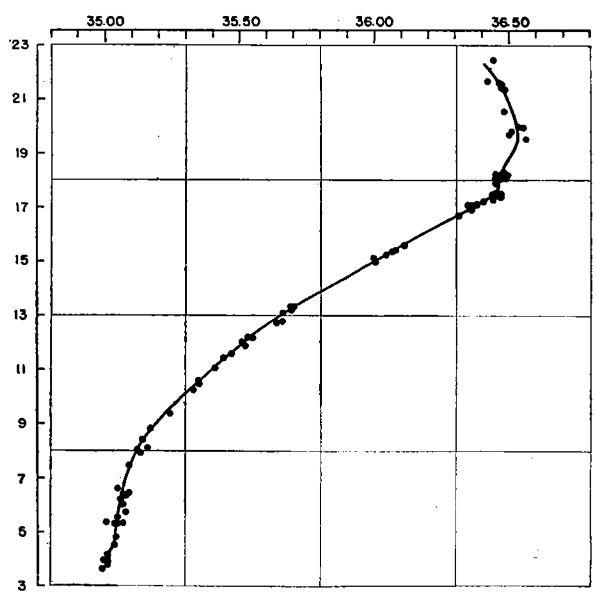

FIG. 13. Temperature salinity relationship at "Atlantis" Station 2887.

[11] Because of the necessity of using different reference levels to compute dynamic heights in the two regions comparisons such as the above apply only generally. Comparisons of the water columns for the two regions from identical reference levels would, no doubt, show somewhat modified results.

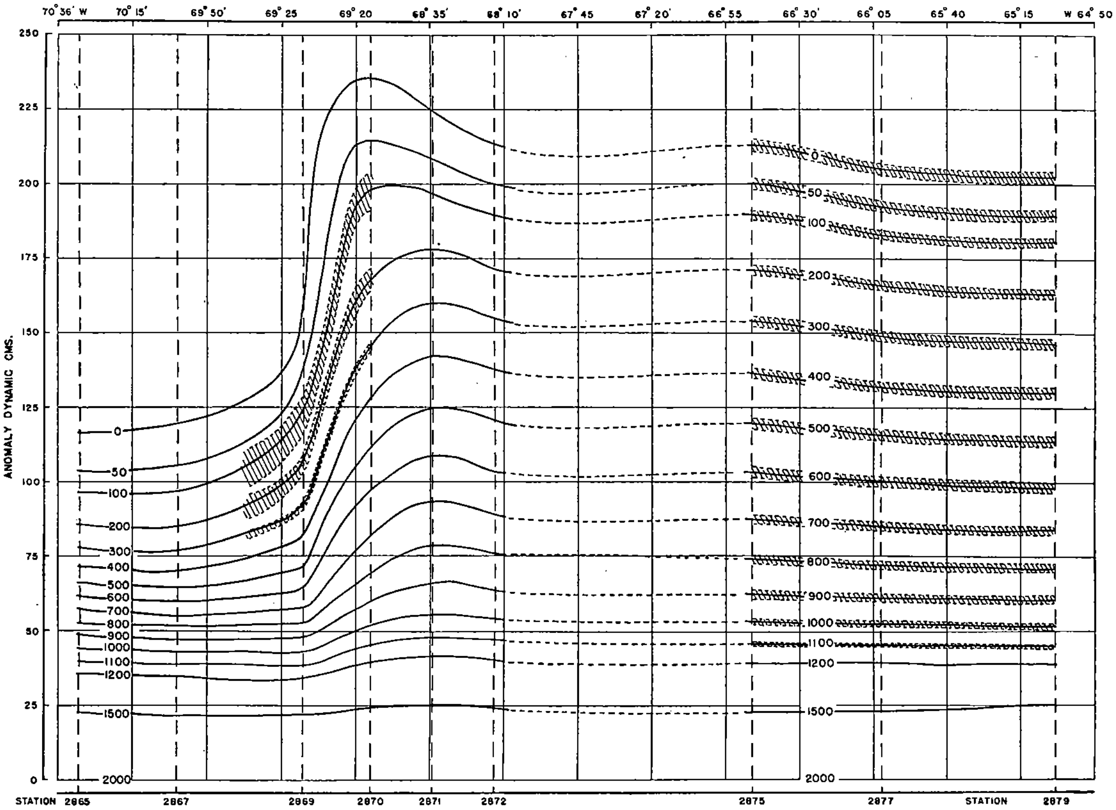

FIG. 14. Dynamic slopes of standard isobaric surfaces (from 2000 decibar surface) across the Gulf Stream as determined by "Atlantis" Stations 2865 (39° 24'N, 70° 33'W) to 2872 (36° 43'N, 68° 13'W) and over the Western Sargasso Sea as determined by Stations 2875 (35° 21'N, 66° 46'W) to 2879 (32° 50'N, 65° 03'W). Shaded areas represent range of short period fluctuations in dynamic height observed in the Gulf Stream at Station 2855 and in the Western Sargasso Sea at Station 2887.

TABLE 8

PRESSURE DECIBARS	*A* 4/18/37 $21^h\,31'$	$\Delta = B - A$	*B* 4/19/37 $03^h\,23'$	$\Delta = C - B$	*C* 4/19/37 $11^h\,23'$	$\Delta = D - C$	*D* 4/19/37 $15^h\,21'$	Cms range
100	67.55	12.95	80.50	−6.60	73.90	−2.25	71.65	12.95
150	51.25	10.45	61.70	−7.40	54.30	−0.05	54.25	10.45
200	39.10	7.45	46.55	−7.20	39.35	1.95	41.30	7.45
250	30.55	4.65	35.20	−4.80	30.40	1.60	32.00	4.80
300	24.20	2.30	26.50	−2.75	23.75	1.35	25.10	2.75
350	19.05	0.90	19.95	−1.45	18.50	1.05	19.55	1.45
400	14.60	0.40	15.00	−0.75	14.25	0.80	15.05	0.80
450	10.60	0.35	10.95	−0.50	10.45	0.65	11.10	0.65
500	6.90	0.30	7.20	−0.35	6.85	0.45	7.30	0.45
550	3.40	0.15	3.55	−0.15	3.40	0.20	3.60	0.20
600	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Time variations in anomaly of dynamic height (from the 600 decibar surface) in the Gulf Stream at Station 2885 during the period $21^h\,31'$, April 18 to $15^h\,21'$, April 19, 1937.

EFFECT OF SHORT PERIOD VARIATIONS OF OCEANOGRAPHIC CHARACTERISTICS ON DYNAMIC COMPUTATIONS

Dynamic Topography and Currents

From a practical oceanographic standpoint the significance of short period variations of oceanographic characteristics is relative, depending on the average horizontal distributions of the properties in question; variations of a certain magnitude that may be of consequence in one region may be insignificant in another. This is brought out in the following by comparison of two hydrographically dissimilar regions; e.g., the Western Sargasso Sea and the Gulf Stream.

TABLE 9

Isobaric Sheet	A	$\Delta=B-A$	B	$\Delta=C-B$	C	$\Delta=D-C$	D
100–150	16.30	2.50	18.80	0.80	19.60	−2.20	17.40
150–200	12.15	3.00	15.15	−0.20	14.95	−2.00	12.95
200–250	8.55	2.80	11.35	−2.40	8.95	0.35	9.30
250–300	6.35	2.35	8.70	−2.05	6.65	0.25	6.90
300–350	5.15	1.40	6.55	−1.30	5.25	0.30	5.55
350–400	4.45	0.50	4.95	−0.70	4.25	0.25	4.50
400–450	4.00	0.05	4.05	−0.25	3.80	0.15	3.95
450–500	3.70	0.05	3.75	−0.15	3.60	0.20	3.80
500–550	3.50	0.15	3.65	−0.20	3.45	0.25	3.70
550–600	3.40	0.15	3.55	−0.15	3.40	0.20	3.60

Summary of time variations in anomaly of dynamic thickness (centimeters) of standard isobaric sheets at "Atlantis" Station 2855, during $21^h 31'$, April 18 to $15^h 21'$, April 19, 1937. *A, B, C,* and *D* designations refer to times indicated in Table 8.

Western Sargasso Sea

For the present discussion, the structural arrangement of the region is based on a profile of "Atlantis" Stations: 2875 (35° 21'N, 66° 46'W), 2877 (34° 09'N, 66° 02'W) and 2879 (32° 50'N, 65° 03'W) obtained during July 7 and 8, 1938 (Figs. 14 and 16).[12] Calculations of dynamic height anomalies of standard isobaric surfaces (from a reference level of 2000 decibars; tabulated in Table 10), between Stations 2875 and 2877, show a decrease in dynamic height of the sea surface of 7.95 dynamic centimeters, and, between Station 2877 and 2879 a decrease of 2.88 dynamic centimeters. Thus, a short period variation of 3.9 centimeters (such as occurred within a few hours at Station 2887; Table 9) would be sufficient to cause discrepancies between 49 and 139 per cent in calculations of dynamic

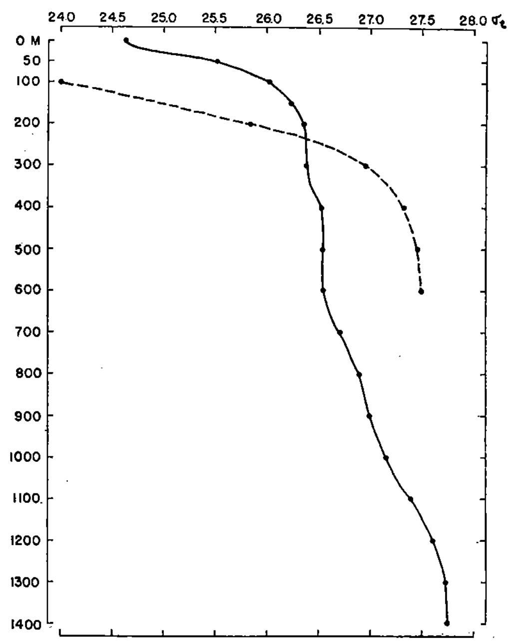

Fig. 15. Vertical distribution of density (σ_t) at Station 2887 (full line) in the Western Sargasso Sea, and at Station 2855 (dashed line) in the Gulf Stream (off the Florida coast).

[12] Stations 2876 and 2878 omitted from this profile as not being necessary to this discussion.

heights of the sea surface in this region. Variations within the water column are of the same order of magnitude, as for instance, may be brought out by comparison of the differences in dynamic thickness of standard isobaric sheets between these stations with the average time change in thickness of identical sheets at Station 2887 (Tables 6 and 10). Thus, between Stations 2875 and 2877, the decrease in thicknesses was generally 0.8 to 2.8 times, and, between Stations 2877 and 2879, 0.09 to 3.0 times the average time change in thickness for individual sheets at Station 2887.

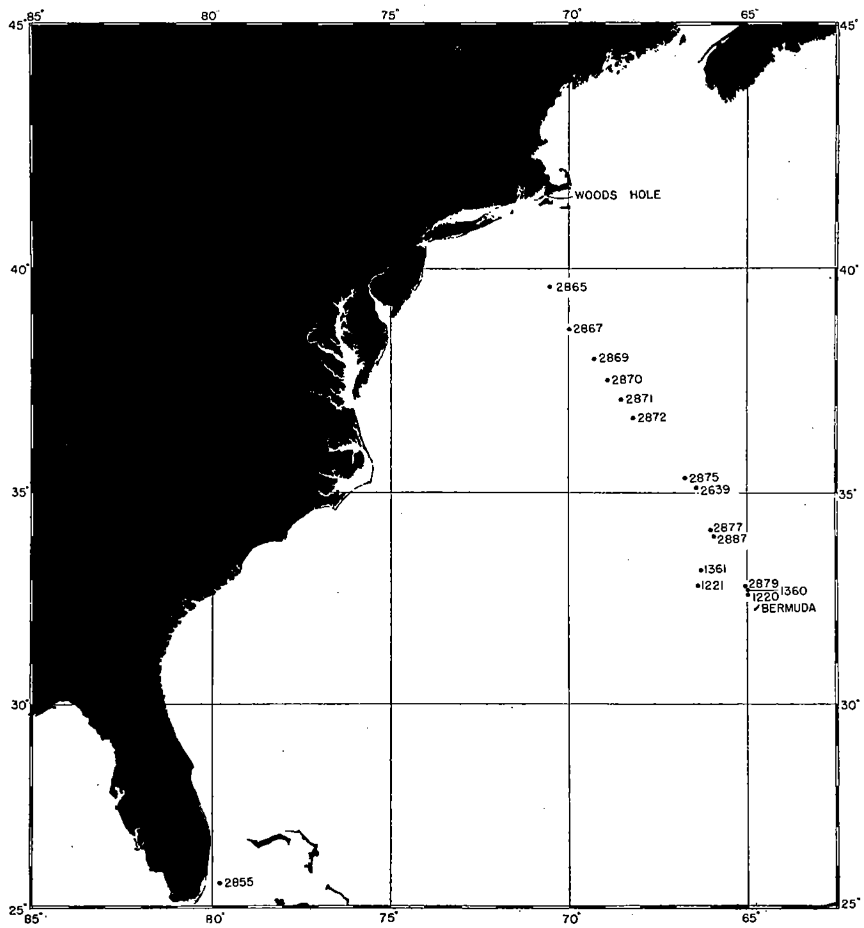

FIG. 16. "Atlantis" stations in the western North Atlantic used in this discussion.

The foregoing computations of time variations in dynamic heights serve to show for this particular region (Western Sargasso Sea) the magnitudes of the discrepancies that are to be expected in computed current velocities. As an illustration, we may compare the vertical variation of current velocity (C) normal to a line between "Atlantis" Stations 2875 and 2877[13] (computed from average dynamic slopes of the isobaric surfaces, referred to the 2000 decibar surface, curve A, Fig. 17) with four cases of vertical variations of

[13] Due to the great horizontal distance between these stations calculated velocities, are of little absolute significance; however they bring out the relative importance of short period variations to computations of this type.

current velocity calculated from time variations in dynamic heights of isobaric surfaces (relative to the 1200 decibar level) at Station 2887; using identical values of distance and latitude. For this computation:

$$C = \frac{1}{2\omega \sin \phi} \cdot \frac{D_{2877} - D_{2875}}{L}$$

the distance, L, between Stations 2875 and 2877, was 137.0 kilometers, and the mean latitude, ϕ, 34° 45′N. Absolute variations in computed current velocities, such as might be brought about by time changes in dynamic heights of isobaric surfaces during approximate $3\frac{1}{2}$ hour intervals at Station 2887[14] were up to 3.5 cms/sec, or about 50 per cent

TABLE 10

	Station 2875		2877 Minus 2875		Station 2877		2879 Minus 2877		Station 2879	
Pressure D-bars	Anomaly Dyn. thickness cms	Anomaly Dyn. height cms	Height Δ cms	Thickness Δ cms	Anomaly Dyn. thickness cms	Anomaly Dyn. height cms	Height Δ cms	Thickness Δ cms	Anomaly Dyn. thickness cms	Anomaly Dyn. height cms
1		213.55	−7.95			205.60	−2.88			202.73
	13.03			−0.50	12.53			−0.02	12.55	
50		200.53	−7.45			193.08	−2.90			190.18
	10.28			−0.90	9.38			−0.15	9.23	
100		190.25	−6.55			183.70	−2.75			180.95
	18.50			−1.10	17.40			−0.05	17.35	
200		171.75	−5.45			166.30	−2.70			163.60
	17.55			−0.40	17.15			−0.35	16.80	
300		154.20	−5.05			149.15	−2.35			146.80
	17.20			−0.30	16.90			−0.45	16.45	
400		137.00	−4.75			132.25	−1.90			130.35
	16.90			−0.70	16.20			0.05	16.25	
500		120.10	−4.05			116.05	−1.95			114.10
	16.50			−0.80	15.70			−0.10	15.60	
600		103.60	−3.25			100.35	−1.85			98.50
	15.55			−0.65	14.90			−0.65	14.25	
700		88.05	−2.60			85.45	−1.20			84.25
	13.70			−0.70	13.00			−0.30	12.70	
800		74.35	−1.90			72.45	−0.90			71.55
	11.55			−0.70	10.85			−0.05	10.80	
900		62.80	−1.20			61.60	−0.85			60.75
	9.45			−0.55	8.90			−0.25	8.65	
1000		53.35	−0.65			52.70	−0.60			52.10
	7.55			−0.25	7.30			−0.30	7.00	
1100		45.80	−0.40			45.40	−0.30			45.10
	6.45			−0.30	6.15			−0.15	6.00	
1200		39.35	−0.10			39.25	−0.15			39.10
	16.35			−0.60	15.75			−0.15	15.60	
1500		23.00	0.50			23.50	2.00			23.50
	23.00			−0.50	23.50			0.00	23.50	
2000		0.00	0.00			0.00	0.00			0.00

Summary of dynamic calculations (reference level, 2000 decibars) for "Atlantis" Stations in Western Sargasso Sea: 2875 (35° 21′N, 66° 46′W), 2877 (34° 09′N, 66° 02′W) and 2879 (32° 50′N, 65° 03′W).

of the computed surface velocity between Stations 2875 and 2877. And in deeper water percental discrepancies may be still greater; ranging up to approximately 200 per cent at 1000 meters.

Similarly, information from Station 2887[15] applied to computed current velocities

[14] I, 10^{h} 25′–13^{h} 01′, June 24; II, 16^{h} 02′–18^{h} 28′, June 24; III, 01^{h} 37′–04^{h} 05′, June 25; and, IV, 04^{h} 05′–07^{h} 33′, June 25. Computations involving dynamic height variations at Station 2887 refer to 1200 meter reference level as compared to a 2000 meter reference level used for other stations.

[15] For this case, L, and ϕ (of equation 7), are based on location of Stations 2877 and 2879.

between Stations 2877 and 2879 (mean latitude: $\phi = 33° \ 30'$N; $L = 152.9$ km (Fig. 18) shows the possibility of discrepancies of more than 100 per cent characterizing the entire water column.

Gulf Stream

Short period time variations of dynamic heights at Station 2855 (page 16) when transposed to the dynamic pattern of this current system (based on a profile of six "Atlantis" Stations, transverse to the current, extending south 33° east from Montauk Point:[16] 2865, 39° 23.5'N, 70° 33'W; 2867, 38° 41'N, 70° 00'W; 2869, 38° 02'N, 69° 18'W; 2870, 37° 34'N, 68° 55'W; 2871, 37° 08'N, 68° 34'W; 2872, 36° 43'N, 68° 13'W; June 4–6, 1937; Fig. 16) may be shown to be of less relative significance than in the Western Sargasso Sea. Anomalies of dynamic height (computed from 2000 decibar surface) are illustrated by Figure 14, shaded areas over the 100, 200, and 300 decibar surfaces represent 24-hour ranges in elevation deduced from continuous measurements at Station 2855.[17] The main part of the Gulf Stream is well marked by the strong dynamic slope between Stations 2867 and 2870 (131 km.); numerical differences in dynamic height being tabulated under the Δ column of Table 11.

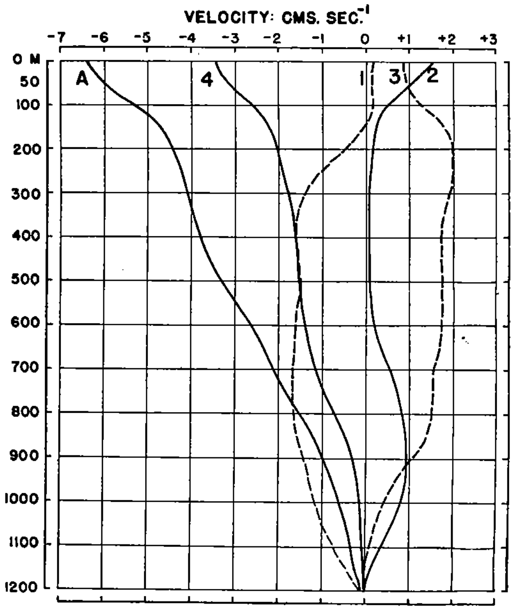

FIG. 17. A = vertical variation of current velocity (cms/sec) normal to a line a connecting "Atlantis" Stations 2877 (34° 09'N, 66° 02'W) and 2875 (35° 21'N, 66° 46'W), in the Western Sargasso Sea, relative to the 2000 decibar surface, compared with variations in the calculated velocity as may be brought about by observed time changes in dynamic heights of isobaric surfaces (referred to the 1200 decibar surface) during approximate $3\frac{1}{2}$ hour intervals at Station 2887; thus: $1 = 10^h\ 25'–13^h\ 01'$, June 24; $2 = 16^h\ 02'–18^h\ 28'$, June 24; $3 = 01^h\ 37'–04^h\ 05'$, June 25; and $4 = 04^h\ 05'–07^h\ 33'$, June 25.

Assuming the permissibility of comparisons of these data (because of similarities in dynamic slope of different parts of the Gulf Stream) the expectancy of short period variations in computed dynamic heights of isobaric surfaces in the Gulf Stream (Table 11) is less than in the Western Sargasso Sea. Thus, across the Gulf Stream, the 100 decibar surface had an average slope (over a horizontal distance of 131 kilometers) of 0.76 dynamic centimeters per kilometer which (according to information from Station 2855) would be subject to short period variation of about 13 per cent, whereas this same surface in the Western Sargasso Sea, with an average slope from 0.044 to 0.016 dynamic centimeters per kilometer (over horizontal distances of 149 to 172 kilometers) may be subjected to variations ranging from 50 to more than 100 per cent.

Calculated current velocities, normal to the "Atlantis" section across the Gulf Stream (off Montauk Point), are illustrated by Figure 19; the results being subject to variations proportional to time variations in dynamic heights of isobaric surfaces. For purposes of

[16] Stations 2866 and 2868 are omitted from this profile because of the extrapolation necessary to compute dynamic heights from the 2000 decibar surface; to have included them, or Stations 1172 and 1173, further south, would not significantly have affected the results.

[17] These data, coming from different parts of the Gulf Stream are not exactly comparable, but no continuous measurements have been made for this current system other than in the Florida Straits.

TABLE 11

Pressure D-Bars	Δ Dyn. cms	Station 2855 Range	Per Cent Variation in Dynamic Slope
0	115.825		
50	109.725		
100	100.300	12.95	12.91
200	83.100	7.45	8.97
300	68.500	2.75	4.01
400	57.550	0.80	1.39
500	46.250	0.45	0.97
600	35.550		
700	25.950		
800	17.950		
900	12.100		
1000	8.300		
1100	6.000		
1200	4.750		
1500	2.500		
2000	0.000		

Horizontal variation in dynamic height across the Gulf Stream (from a 2000 decibar reference surface) off Montauk point over a distance of 131 kilometers; column: Δ dyn. cms.=dynamic heights at Station 2867 (38° 41′N, 70°00′W) minus dynamic heights at Station 2870 (37° 34′N, 68° 55′W); column: Station 2855 range=maximum time variation in dynamic heights of these surfaces (from the 600 decibar surface) during an approximate 24-hour period; column: per cent variation$=100\left(\frac{\text{range}}{\Delta}\right)$.

illustration, velocity variations as would be induced by short period changes in dynamic heights of isobaric surfaces during the intervals: 21^h 31′ April 18 to 03^h 23′ April 19, 03^h 23′ to 11^h 23′ April 19 and 11^h 23′ to 15^h 21′ April 19, at Station 2855 (using the same constants in the velocity equation as for Stations 2869–2870), are compared with calculated vertical variations of velocities normal to lines connecting Stations 2867–2869, 2869–2870 and 2870–2871 (Fig. 20). Thus, for instance, at the 100 decibar surface, between Stations 2869 and 2870, the maximum short period change is less than 20 per cent of that computed (135 cms/sec) whereas, between Stations 2867 and 2869, it would amount to more than 50 per cent (30 cms/sec). This effect, within the Gulf Stream, will be greatest where horizontal velocities are least; a situation which, in particular, affects computations near boundaries of the Gulf Stream and its weaker counter currents. Furthermore, because vertical structure of the water column in the two parts of the Gulf Stream are not identical (Fig. 15), and because of differences in depth of the reference levels (used as a basis for computation) departures of current velocity seemingly fall off too rapidly with depth (for the Montauk Point section) so that somewhat greater percental departures will be expected to oc-

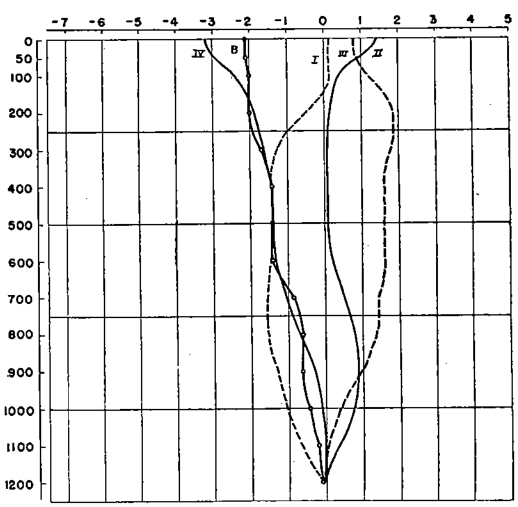

FIG. 18. A=vertical variation of current velocity (cms/sec) normal to a line connecting "Atlantis" Stations 2879 (32° 50′N, 65° 03′W) and 2877 (34° 09′N, 66° 02′W), in the Western Sargasso Sea, relative to the 2000 decibar surface, compared with variations in the calculated velocity as may be brought about by observed time changes in dynamic heights of isobaric surfaces (referred to the 1200 decibar surface) during approximate 3 hour intervals at Station 2887; thus: 1 = 10^h 25′–13^h 01′, June 24; 2 = 16^h 02′–18^h 28′, June 24; 3 = 01^h 37′–04^h 05′, June 25; and 4 = 04^h 05′–07^h 33′, June 25.

cur in the deeper water than those represented here (Fig. 20); and near the boundaries of currents, where velocities are weakest (Fig. 19), the situation may be somewhat as illustrated for the Western Sargasso Sea (Figs. 17 and 18).

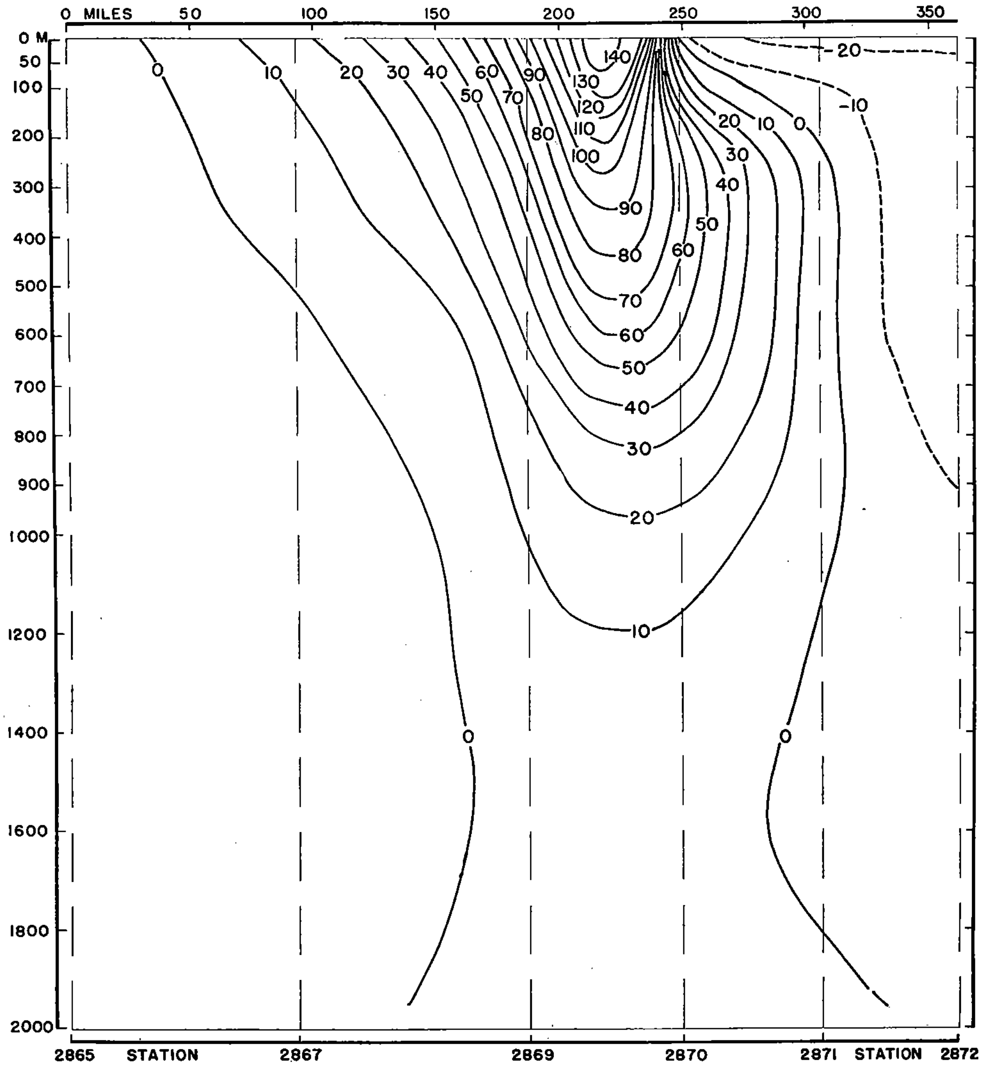

FIG. 19. Calculated current velocities (cms/sec), based on an "Atlantis" profile approximately normal to the axis of the Gulf Stream.

VOLUME TRANSPORT

It can be shown that the volume transport, above a surface of zero geopotential, between two verticals (A and B) in the sea is closely given by the formula:[18]

[18] This equation, derived by Jakelln (1936), gives results of volume transport essentially similar to that derived by Werenskiold (1935):

$$V=\frac{g}{2\alpha_0\omega \operatorname{Sin}\phi}\int_0^{z^2}(\alpha-\alpha_0)\, d(z^2)$$

$$V = \frac{10}{2\omega \sin \phi} (\mathcal{Q}_A - \mathcal{Q}_B) m^3 \text{ sec}^{-1}$$

where

$$\mathcal{Q} = \int_z^0 Ddz \; m^3 \text{ sec}^{-2}$$

the dynamic height, D, above the surface of zero potential being:

$$D = \int_p^0 \alpha dP$$

ω, is the angular velocity of the earth's rotation and, ϕ, the mean latitude between A and B. Thus:

$$2\omega \sin \phi = 14.58 \times 10^{-4} \sin \phi.$$

Transforming the above equation for $\mathcal{Q}$, in terms of anomalies, its values are designated as $\Delta\mathcal{Q}$, and

$$\Delta\mathcal{Q} = \int_z^0 \Delta Ddz$$

where ΔD is the anomaly of dynamic height. $\Delta\mathcal{Q}_A$–$\Delta\mathcal{Q}_B$ is designated as $\Delta'\mathcal{Q}$.

A previous investigation of short period variations of oceanographic elements on volume transport calculations in the Western Sargasso Sea, by means of separate comparisons of calculated total transport between "Atlantis" Station 1226 (35° 07'N, 71° 53'W; eastern edge of the Gulf Stream) and two independent series of observations at "Atlantis" Station 2639 (35° 07'N, 66° 25'W, about 180 miles northwest of Bermuda), gave results differing by 43 per cent of the larger;[19] a startling result, the gravity of which needs be considered in studies of water transports in the sea.

Western Sargasso Sea

The data of the present discussion permit additional information to be brought out on the magnitude of discrepancies liable to occur in calculations of water transports. Thus, the calculated time variation of $\Delta\mathcal{Q}$ (referred to 1200 decibars) during a 24-hour period (beginning 07^h 57', June 24) at Station 2887 (Table 12) had an average value:

$$(\Delta\mathcal{Q})_M = 948.521 m^3 \text{ sec}^{-2}$$

the average absolute change between series of observations was:

$$(\Delta'\mathcal{Q}) = 8.533 m^3 \text{ sec}^{-2}$$

the average absolute hourly change (over the 24-hour period) was:

$$(\Delta'\mathcal{Q}) = 2.905 m^3 \text{ sec}^{-2}$$

and the maximum $\Delta\mathcal{Q}$ difference ($\Delta'\mathcal{Q}$) between any two series was:

$$(\Delta'\mathcal{Q})_{\max} = 30.000 m^3 \text{ sec}^{-2}.$$

[19] This difference in transport was incorrectly stated to be 70.3% (Seiwell, 1937). Computed volume transports between Stations 1226–2639C and 1226–2639H are 8.081×10^6 and 14.190×10^6 m^3 sec^{-1}.

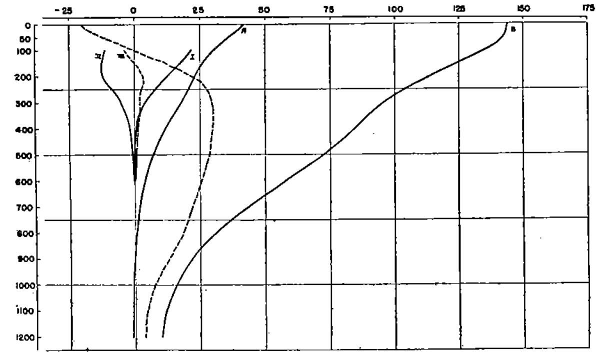

FIG. 20. Vertical variation of calculated current velocities in the Gulf Stream, referred to the 2000 decibar surface; A = velocity normal to the line connecting Stations 2867 (38° 41′N, 70° 00′W) and 2869 (38° 02′N, 69° 18′W), B = velocity normal to the line connecting Stations 2869 and 2870 (37° 34′N, 68° 55′W), C = velocity normal to the line connecting Stations 2870 and 2871 (37° 08′N, 68° 34′W), compared with variations in the calculated velocities as may be brought about by observed time variations in dynamic heights of isobaric surfaces (referred to the 600 decibar surface) during three different intervals at Station 2855; thus: I = 21ʰ 31′, April 18–03ʰ 23′, April 19, II = 03ʰ 23′–11ʰ 23′, April 19, III = 11ʰ 23′–15ʰ 21′, April 19, 1937.

The consequence of these results to transport computations is relative (as for current computations), depending on $\Delta'\mathcal{Q}$ variations in the area. The effect is variable and while largest recorded variations of $\mathcal{Q}$ or $\Delta\mathcal{Q}$ are not the usual rule (Table 12) they occur with sufficient frequency so that even occasional large errors in transport computations from uncontrolled data may vitiate, or at least seriously interfer with, conclusions of regional and seasonal differences in transport.

Evaluations of horizontal changes in $\Delta\mathcal{Q}$ ($\Delta'\mathcal{Q}$) in the Western Sargasso Sea are based on four groups of "Atlantis" Stations (Fig. 16): 2875 (35° 21′N, 66° 46′W; June 7, 1937), 2877 (34° 09′N, 66° 02′W; June 8, 1937), 2879 (32° 50′N, 65° 03′W; June 8, 1937), 1220 (32° 40′N, 65° 00′W; April 17, 1932), 1221 (32° 51′N, 66° 25′W; April 18, 1937), 1360 (32° 43′N, 65° 00′W; August 28, 1932), and 1361 (33° 13′N, 66° 20′W; August 28, 1932); and, as tabulated in Table 13, the values, V/L, or total transports, divided by the linear distances between stations, are comparable. The average (based on average $\Delta'\mathcal{Q}$ value of 53.614 m^3 sec^{-2} over an average horizontal distance of 148.0 kilometers for the mean latitude of the stations) for all pairs of stations considered is:

$$\frac{V}{L} = -\ 47.98 m^3\ \text{sec}^{-1}\ \text{per}\ m$$

TABLE 12

Station 2887 Series	Time (6/24/37)	$\Delta\mathcal{Q}$	($\Delta'\mathcal{Q}$)
A	07ʰ 57′	952.975	
			2.215
B	10ʰ 25′	955.190	
			−14.715
C	13ʰ 01′	940.475	
			− 4.575
D	16ʰ 02′	935.900	
			6.015
E	18ʰ 28′	941.915	
			5.000
F	22ʰ 12′	946.915	
			1.360
	(6/25/37)		
G	01ʰ 37′	948.275	
			17.625
H	04ʰ 05′	965.900	
			−16.760
I	07ʰ 33′	949.140	

Summary of $\Delta\mathcal{Q}$ time variations at "Atlantis" Station 2887 in the Western Sargasso Sea (based on a reference surface of 1200 decibars); $\Delta'\mathcal{Q}$ represents change of $\mathcal{Q}$ or $\Delta\mathcal{Q}$ between successive observation series.

TABLE 13

STATION	$\Delta\mathcal{Q}$, m^3 sec^{-2}	$\Delta'\mathcal{Q}$	V, m^3 sec^{-1}	L, Km	V/L, m^3/sec per m
2875	1478.055				
		− 38.140	− 4,588,240	149.0	− 30.79
2877	1439.915				
		− 19.120	− 2,376,620	172.2	− 13.80
2879	1420.795				
1220	1329.338				
		−107.687	−13,654,700	134.4	−101.60
1221	1437.025				
1360	1340.065				
		− 49.510	− 6,238,260	136.4	− 45.74
1361	1389.575				

Summary of volume transport calculations in Western Sargasso Sea, based on four pairs of "Atlantis" Stations: 2875 (35° 21'N, 66° 46'W; June 7, 1937), 2877 (34° 09'N, 66° 02'W; June 8, 1937), 2879 (32° 50'N, 65° 03'W; June 8, 1937), 1220 (32° 40'N, 65° 00'W; April 17, 1932), 1221 (32° 51'N, 66° 25'W; April 18, 1937), 1360 (32° 43'N, 65° 00'W; Aug. 28, 1932), and 1361 (33° 13'N, 66° 20'W; Aug. 28, 1932). Column: $\Delta\mathcal{Q}$, m^3 sec^{-2}, gives anomalies of $\mathcal{Q}$ calculated from the 2000 decibar surface; column: $\Delta'\mathcal{Q}$, the horizontal change of $\mathcal{Q}$ between pairs of stations; column: V, m^3 sec^{-1}, the calculated volume transport between pairs of stations; column: L, Km, the horizontal distance between stations; and, column: V/L, m^3 sec per m, average volume transport per meter between stations (an index for comparison). The negative sign indicates southerly transport.

which may be the best value of transport per linear meter between latitudes 35° 21'N, 32° 40'N and longitudes 65° 00'W–66° 46'W. Variations in $\Delta\mathcal{Q}$, V and V/L (Table 13) result from local, annual, seasonal, and short period variations of oceanographic elements, the partial effects of long period and local components are overshadowed by the superimposed short period variations.

Comparison of horizontal $\Delta\mathcal{Q}$ variations ($\Delta'\mathcal{Q}$; Table 13) in the Western Sargasso Sea, with time $\Delta\mathcal{Q}$ variations (during a 24-hour period) at Station 2887 (Table 12) shows that maximum $\Delta\mathcal{Q}$ difference between any two sets of observations at Station 2887 (30.00 m^3 sec^{-2}) was nearly 56 per cent of the average $\Delta'\mathcal{Q}$ value in the Western Sargasso Sea, and between 28 and 157 per cent of individual horizontal $\Delta\mathcal{Q}$ differences ($\Delta'\mathcal{Q}$). The average change of $\Delta\mathcal{Q}$ between observation series at Station 2887 (8.533m^3 sec^{-2}) was 16 per cent of the average horizontal $\Delta'\mathcal{Q}$ value and from 8 to 45 per cent of the individual values.

Gulf Stream

The horizontal variation of $\Delta\mathcal{Q}$ ($\Delta'\mathcal{Q}$) per unit distance across the Gulf Stream off Chesapeake Bay ($\Delta'\mathcal{Q}$ = 640.160 m^3 sec^{-2} over 213.9 kilometers; Table 14) was more than eight times that in the Western Sargasso Sea (average $\Delta'\mathcal{Q}$ = 53.614 m^3 sec^{-2} over 148 kilometers); and its maximum value (444.010 m^3 sec^{-2} over 62 kilometers) was nearly

TABLE 14

STATION	MEAN LATITUDE	$\Delta\mathcal{Q}$ m^3 sec^{-2}	$\Delta'\mathcal{Q}$	V m^3 sec^{-1}	L, Km	V/L
2865		917.890				
	39°03'		−12.905	-1.4067×10^6	92.7	−15.17
2867		904.985				
	38°22'		95.795	10.5949×10^6	94.6	112.00
2869		1000.780				
	37°48'		444.010	49.6847×10^6	62.0	801.37
2870		1444.790				
	37°21'		100.355	11.3401×10^6	57.2	198.25
2871		1545.145				

Summary of volume transport calculations (from a 2000 decibar reference level) for the Gulf Stream off Chesapeake Bay. For explanation see legend of Table 13 and text.

nine times the maximum recorded for the latter region (107.687 m^3 sec^{-2} in 134.4 kilometers); and (after correcting for differences in latitude; Fig. 16), the average volume transport per meter of the Gulf Stream ($V/L = 370.54$) was 7.7 times the average for the Western Sargasso Sea ($V/L = 47.98$), and its maximum ($V/L = 801.37$), approximately eight times the maximum ($V/L = 101.60$) for the latter region. The total volume transport of the Gulf Stream between Stations 2867 and 2871 is calculated to be 71.62 m^3 sec^{-1}, which is 11.4 per cent less than the Gulf Stream transport off Chesapeake Bay as calculated by Iselin (1936) for April 1932 ($82 \times 10^6 m^3$ sec^{-1}). This disparity may have been due to variable station spacing, to differences in methods, or to annual and seasonal variations, etc; but it is no greater than could have resulted from short period variations of temperature and salinity.

Combination of previous considerations indicate that discrepancies in volume transport computations for the Gulf Stream, will (like current computations) be less than in the Western Sargasso Sea (or dynamically similar regions), and that within the Gulf Stream system larger percental departures are to be expected in computations involving transports of the counter currents. Thus, maximum time variation of $\Delta\mathcal{Q}$ at Station 2887 (30.000m^3 sec^{-2}) represents between 7 and 31 per cent of the $\Delta\mathcal{Q}$ change across the Gulf Stream proper, but approximately two and one half times the $\Delta\mathcal{Q}$ change between Stations 2865 and 2867 (Fig. 14 and 19). Time variations of $\mathcal{Q}$ or $\Delta\mathcal{Q}$ at Station 2855 (in the Florida Straits) are only of general interest in this connection because of the necessity of using the 600 decibar surface as the reference level for computation; the maximum $\Delta\mathcal{Q}$ variation during the 19-hour period (21^h 31′, 4/18 to 15^h 21′, 4/19/37) being 16.92 m^3 sec^{-2}.

RÉSUMÉ AND CONCLUSIONS

As a result of short period variations of oceanographic characteristics at fixed depths in the sea, a measure of average conditions is not generally obtained from isolated individual samplings of the water column, a circumstance which reduces the significance of patterns of geographic variation (as deduced from data of station networks).

Measurements of short period variations of temperature in the Western Sargasso Sea (based on six days of observations at Station 2887) showed an average daily temperature range at fixed depths (surface to 1200 meters) of 0.30° to 1.26°; an average absolute hourly variation of 0.011° to 0.253°; and an average absolute variation between successive samplings (of the water column) of 0.016° to 0.361°. Similar changes (at fixed depths) also characterize salinity (and other properties of sea water), and, thus, cause time variations in calculated dynamic depths (or heights) of isobaric surfaces along fixed verticals which (because of vertical variations in amplitude and phase of the internal wave mechanism) change with depth. Time changes in computed dynamic heights of the sea surface, up to 3.90 dynamic centimeters, have been found to occur within a three and one half hour interval; such changes as computed for the sea surface, however, are not proportional to those of deeper lying isobaric surfaces. Thus, between two series of observations (approximately two and one half hours apart), at Station 2887, the computed dynamic height of the sea surface increased 0.20 dynamic centimeters while that at the 700 and 800 decibar surfaces decreased 1.90; but, still later (during an approximately three and one half hour interval), dynamic height of the sea surface decreased 3.90 dynamic centimeters while that of the 800 decibar surface decreased only 0.80.

The significance of short period variations of oceanographic characteristics to practical oceanography depends on the ratio of the amplitude of time change to the average permanent topography of the properties in question; and time variations of consequence in one region may be relatively insignificant in another. Thus, computations of dynamic heights of isobaric surfaces in the Western Sargasso Sea (from "Atlantis" Stations 2875, 2877, and 2879) give differences between stations, in dynamic elevation of the sea surface (from 2000 decibars), of 2.88 and 7.95 dynamic centimeters, or 0.74 to 2.04 times the computed time change in dynamic height of the sea surface, between two series of observations (3.9 centimeters; within three and one half hours at Station 2887) which is sufficient (in this region) to produce a discrepancy in dynamic calculations of 49 to 135 per cent. The differences in dynamic thickness of isobaric sheets between stations, in the Western Sargasso Sea, was 0.09 to 3.0 times the average time change of thickness of identical sheets, between individual samplings at Station 2887. Computations of current velocities will be affected in similar proportions; calculated time variations in dynamic height at Station 2887 being sufficient to bring about variations of 3.0 to 3.5 cms/sec in the computed velocities between Stations 2875, 2877, and 2879, or about 50 per cent of that between 2875 and 2877 and over 100 per cent of that between 2877 and 2879 (page 19; footnote 12). In deeper water, with slower velocities, percental variations increase (obtaining approximately 200 per cent at 1000 meters depth).

It is, thus, obvious that when observed differences in computed dynamic heights of isobaric surfaces, between pairs of verticals, are of the same order of magnitude as the time variations themselves, little significance can be attached to the results. On the other hand, since largest time variations are not the usual rule (as brought out by frequency distributions of temperature departures; page 10), the trends of dynamic topography (and resulting computations of currents, etc.) as shown by observations over a network of stations, may, even in cases where much of the detail is insignificant, be unaffected. Furthermore, as brought out by the above, discrepancies in dynamic computations frequently will be greater within the water column than at the surface.

Volume transports of water in the Western Sargasso Sea (based on 4 groups of "Atlantis" Stations: 2875–2877, 2877–2879, 1220–1221, and 1360–1361) gave an average value of 47.98 m^3 per second per linear meter; the changes in $\Delta\mathfrak{Q}$ between stations ranged from 19.120 to 107.687 m^3 sec^{-2} over distances of 134.4 to 172.2 kilometers; the average being $\Delta\mathfrak{Q} = 53.614$ m^3 sec^{-2} for 148 kilometers. Comparison with Station 2887 shows the maximum $\Delta\mathfrak{Q}$ variation during a 24-hour period (30.000 m^3 sec^{-2}) to be equivalent to nearly 56 per cent of the average $\Delta\mathfrak{Q}$ variation ($\Delta'\mathfrak{Q}$) between stations in the Western Sargasso Sea and from 28 to 157 per cent of individual differences between stations. The effect on calculations of volume transport in the region will be proportionate.

Within the Gulf Stream system off the American coast observed short period variations of oceanographic characteristics were of larger magnitude than in the Western Sargasso Sea, but because of the greater slope of isobaric surfaces the consequence to dynamic calculations is relatively less. Thus, between the 100 and 200 decibar surfaces, maximum variations in dynamic height during a 24-hour period at Station 2855 (7.45 to 12.95 cms) were from 2.3 to 4.3 times the maximum variations at similar levels in the Western Sargasso Sea, but when transposed to the Gulf Stream pattern (off Montauk Point) they represent only 9 to 13 per cent of the change in dynamic height of the isobaric surfaces over a distance of 131 kilometers. Variations in calculated current velocities (proportional to amount of change in dynamic heights of isobaric surfaces) in the strongest part of the Gulf Stream at 100 meters (135 cms/sec, between Stations 2869 and 2870) would be less than 20 per cent, whereas between Stations 2867 and 2869, where velocity at 100 meters was computed to be 30 cms/sec, it would amount to more than 50 per cent. Thus, effect of short period changes on current velocities and volume transport computations for the Gulf Stream system will undoubtedly be greatest where horizontal velocities are least; a situation which, in particular, affects computations near current boundaries and the weaker counter currents.

It is certain that oceanographic data used for dynamic computations (or other purposes) need be controlled, and that determination of the average state of the sea is closely linked with short period variations of oceanographic elements. Hence, in execution of field programs, space and time arrangement of samplings should be such as to obtain information on time changes of oceanographic characteristics at fixed depths as well as on geographic variation; several anchor stations (for at least 25 hours of continuous sampling) should be scattered throughout the station network. The minimum number of anchor stations required for sufficient data to permit estimation of significance of observed geographic patterns and to provide limitations on conclusions regarding the average state of the sea need be based on experience and on common sense judgement. In the absence of specific information on the mechanism of internal waves, data from 25-hour anchor stations may, at present, be used either to compare directly computed time variations of dynamic heights of isobaric surfaces with their observed geographic variations (page 19), or to form frequency distributions (page 10) of departures of an element (such as temperature) from average values at standard depths, for approximation of significance of observed horizontal changes of oceanographic elements at similar depths.

In the preceding pages effects of internal waves on dynamic computations have, for practical reasons, been emphasized from the standpoint of the computation itself, and theoretical implications raised by the existence of continuously varying characteristics at fixed depths in the sea have been excluded from discussion. However, in this connection, while the occurrence of internal waves seemingly suggests that motion in the sea is not steady, existing information appears to indicate that the disturbance is insufficient to invalidate computation of the broad general features of ocean currents by the dynamic method of V. Bjerknes. Hence, it is likely that this method will continue to find wide applicability to oceanic problems, and, as a result, it becomes increasingly significant to consider the amount by which current patterns may be distorted because of the phenomenon in question, an object which may be accomplished by modified hydrographic procedure.

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